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From Artwork to Interaction
Gamified Approach to Museum Engagement

MASTER DISSERTATION

Apoorba Majumdar
MASTER OF INTERACTIVE MEDIA DESIGN

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Abstracto

No processo de preservação do patrimônio cultural, existe a dificuldade de manter a atenção de todos os tipos de público, especialmente dos visitantes com menor capacidade de concentração. O uso de tecnologias como a Realidade Virtual (RV), embora cada vez mais comum, nem sempre é devidamente integrado e pode, quando mal utilizado, tornar a experiência mais difícil para o visitante. Museus de arte de menor dimensão, em particular, enfrentam o desafio de captar e sustentar a atenção de públicos diversos. Esta dissertação apresenta The Missing Piece, um jogo educativo em 3D de quebra-cabeças, desenvolvido como protótipo de alta fidelidade em parceria com o Museu Henrique e Francisco Franco, na Madeira, Portugal. Trata-se de uma experiência interativa destinada a atrair potenciais visitantes de forma lúdica; ao mesmo tempo que se envolvem na atividade, os jogadores absorvem informações contextuais sobre os artistas e o patrimônio por meio de elementos visuais e sonoros integrados no jogo. O processo de design levou ao desenvolvimento do jogo em Unity e à sua testagem por meio da System Usability Scale (SUS). Os resultados do inquérito indicam que a experiência foi considerada fácil de jogar, agradável e eficaz em despertar curiosidade sobre o museu. O projeto constitui um bom exemplo de como ferramentas digitais gamificadas podem melhorar a educação cultural e oferecer soluções escaláveis para museus de pequena e média dimensão.

Palavras-chave

Educação Artística, Patrimônio Digital, Gamificação, Museus Virtuais, Avaliação de Usabilidade, Jogos de Quebra-Cabeça, Engajamento Museológico.

Abstract

To preserve the cultural heritage today, traditional institutions struggle to maintain interest in audiences of all types, especially the visitors with shorter attention spans. To engage diverse audiences, the use of technologies like Virtual Reality (VR) has become popular in larger institutions. However, its interactions have not always been integrated seamlessly, making it difficult for people when used incorrectly. Smaller art museums, in particular, face significant challenges in engaging diverse visitors. The primary goal of this dissertation is to present The Missing Piece, a 3D educational puzzle game designed and developed using a high-fidelity prototype in collaboration with The Henrique and Francisco Franco Museum at Madeira in Portugal. The game aims to translate traditional museum environments that are often perceived as cognitively demanding into engaging and enjoyable gameplay mechanics. This experience acts as an icebreaker for potential visitors. Its immersive audio and visuals provide deep insights into artworks and heritage, absorbing them in an activity that seamlessly integrates the museum's contextual information before their visit. This game was designed and developed using Unity and tested by employing the System Usability Scale (SUS) for evaluation. The survey results reveal that the playthrough was user-friendly, engaging, enjoyable and effective in creating curiosity in the museum. The project serves as a compelling example of how gamified digital tools can enrich cultural education and offer scalable solutions for small and medium-sized museums.

Keywords

Art Education, Digital Heritage, Gamification, Virtual Museums, Usability Evaluation, Puzzle Games, Museum Engagement.

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Acronyms

MHFF	Museum of Henrique e Francisco Franco
VR	Virtual Reality
MR	Mixed Reality
2D	Two Dimensions
3D	Three Dimensions
SUS	System Usability Scale
NPRs	Non-photorealistic rendering
VMs	Virtual Museums
AR	Augmented reality
UX	User Experience
GC2	Game Creator 2
HCI	Human Computer Interaction

1. INTRODUCTION

1.1 Motivation

When we began researching museum experiences, the initial challenge we encountered was the observation that the youth are less likely to visit museums. This trend can partly be attributed to the pervasive use of social media and cell phones.[3] For some individuals, it is a rigid process, whereas others feel it requires more time and attention than they can spare. In a landscape dominated by pervasive high-velocity digital content, audiences today have become accustomed to dopamine-driven engagement. Consequently, the passive interpretive model of museum exhibitions, often characterised by static displays and fixed informational structures, may fail to resonate with visitors who find such conventional modes of presentation aesthetically and intellectually unexciting.

This is where VR and interactive digital media offer fresh opportunities in this area. Instead of passively viewing objects, visitors have the opportunity to participate, engage, and interact with them. VR can enhance cultural heritage by making it more immersive, accessible, and memorable. HCI [11] study shows the importance of impactful design museum experiences that promote active engagement. [11].

However, these days, the integration of virtual reality in small and medium-sized museums often falls short [10], of expectations, resulting in confusion or resentment rather than genuine interaction and engagement. Zhou observes that incorporating human interaction into VR museums remains a significant challenge [2]. Researchers highlight that many virtual museums resemble passive video tours rather than offering interactive cultural experiences [3].

The Museum of Henrique e Francisco Franco (MHFF) in Madeira illuminates the essence of this matter. The museum has a collection, which includes digital pictures of the artworks, but it lacks a framework to use these resources effectively. Meetings with the museum's management team revealed that visitor interest can drop quickly if suitable engagement strategies are not implemented. One example we discovered is the City of Sugar Museum, which is managed by the same team and now mainly relies on school visits due to a decline in regular attendance. This highlighted for me the urgent need for museums to explore a strategy that is engaging, interactive, entertaining, and accessible, that resonates with a diverse range of visitors.

Research Questions

To reach a clear conclusion through the research in this dissertation, it was necessary to address the following questions:

1. What approach can be adopted to effectively improve museum engagement?
2. Can a serious game approach successfully integrate educational content regarding artworks into immersive mechanics without becoming cumbersome?

1.2 Contribution

This dissertation is my response to that challenge. It combines playful learning, gamification, and digital museology to design interactive ways of experiencing cultural heritage. The work makes two complementary contributions:

The Game: A 3D puzzle game where players act as digital art restorers. Guided by Ana, a digital curator, they repair fragmented digital paintings and sculptures from the MHFF by solving picture puzzles. With each completed puzzle, part of a virtual museum is restored, gradually unlocking artworks and encouraging exploration. This game is designed not only for children but for all visitors who prefer interactive, hands-on engagement with art rather than passive observation.

The Learning: While entertainment and competition are the main goals of the interaction, the player sees, hears, and retains the museum's art and culture-related information throughout the experience. The gamified approach keeps the player aware of the educational intent, but instead of invoking the tedium associated with traditional schoolwork, they perceive it as a challenge and absorb information naturally.

This dissertation demonstrates how digital technologies can be used to create engaging and meaningful experiences in museums of all sizes, including those with limited funding. The purpose of this dissertation is to supplement traditional exhibitions and provide a gateway that piques interest in a more profound understanding of culture, rather than seeking to replace them.

1.3 Dissertation Structure

The dissertation is organised as follows:

- **Chapter 2: State of the Art –** Reviews existing research on museum engagement, VR, gamification, and interactive storytelling, with relevant case studies in digital heritage.
- **Chapter 3: Methodology –** Outlines the research approach and the nature of the collaboration with the museum.
- **Chapter 4: Method –** Details the design and development process, as well as the evaluation of the study regarding usability, engagement, and learning.
- **Chapter 5: Discussion –** Provides the reasoning for game design choices, analysis of survey results, limitations of the research, and proposals for future development.
- **Chapter 6: Conclusion –** Summarises the project's contributions and its cultural and educational impact.

2. STATE OF THE ART

2.1 Museum Engagement

One effective method to increase visitor engagement is the implementation of participatory programmes. For instance, Museum Lates, events held after-hours, have proven highly successful. The London Museum Lates Visitor Motivation study [26] demonstrates that these informal formats attract a more diverse audience. By removing strict barriers, and mixing social time with learning, these programmes resonate with visitors seeking a balance of entertainment and culture. This shift in institutional programming fosters greater interest among visitors and renders the museum environment significantly welcoming.

Attracting visitors to museums requires a sophisticated communication strategy. Marketing must extend beyond broadcasting announcements to facilitate an active dialogue with the audience. According to the Smithsonian Institution Office of Policy and Analysis effective marketing relies on understanding audience motivations in order to shape public perception [29]. This strategic, visitor-centric approach is critical for transforming the museum experience, increasing attendance and fostering visitor interest.

Museums expand their reach with the help of social media, offering a digital space where the community can participate even after they leave the museum. Ongoing digital communication is essential for maintaining a relationship with the audience. Platforms like Instagram have become integral to the museum experience, acting as a space where people can join a broader conversation. Studies show that many European museums successfully use these tools for continuous engagement [28]. They create compelling content by combining effective storytelling, strong visuals, and community interaction, to maintain continuous engagement that keeps the museum relevant in the public’s mind.

Applying game design to museum exhibits can make learning more engaging. According to De Araújo et al. [27], 'serious games' turn education into an enjoyable experience. This interactive method helps visitors understand the subject better and stay interested in what they are learning. Similarly, advanced technology is helping museums create more engaging experiences by using game elements in Virtual Reality (VR) and Mixed Reality (MR). Research shows these immersive technologies give people strong, emotionally rich cultural experiences and transform the visitor's role; they are no longer just passive observers, but active participants, who can jump into the history or art they are seeing [30].

To conclude this section, modern museums must combine social events, an active online presence, and interactive activities to succeed today. Following this path is essential to stay relevant, accessible, and meaningful for future generations.

Marketing

Today's museums face two challenges: to be connected and accessible to current audiences while simultaneously safeguarding history. To deal with this problem, marketing is no longer just a side task for basic publicity and making announcements. Instead, it has evolved into a key strategy for encouraging real engagement [35].

Museum marketing today has become audience-centric. Rather than just advertising exhibits, campaigns now focus on understanding visitor motivation—why people visit and how they feel about the institution [29]. As McLean [35] suggests, marketing is really about balancing what the museum provides with what the public actually wants. Understanding these motivations is fundamental to creating successful exhibits that attract a wide audience [29].

A major change in museum marketing is the shift toward building direct, personal relationships with the audience. This change is driven by digital platforms. Wilson-Barnao [37] describes this as a move "from visitors to users," where marketing is tailored to what individuals actually like. For example, social media creates a two-way street where visitor feedback helps museums decide which exhibits to showcase and influences how many people attend [36]. By using social media data, museums can adjust their messaging and creative direction to better connect with their targeted audience.

Marketing now plays a major role in how museums are run and operate. By listening to feedback on social media, museums can actually shape their decisions based on what people want [36]. This shows that marketing isn't just about spreading the word. It's a diagnostic tool used to measure public interest, manage public perception and make sure the museum's exhibits match what visitors expect. So, effective marketing is a must-have if a museum wants to keep people interested and engaged over the long term [29].

Social Media

Research shows that social media is no longer just another advertising channel. It has evolved into an indispensable tool for achieving strong audience engagement. In today's context, success isn't just about how many people attend; it's about building lasting relationships and creating two-way conversations with visitors [31]. This shift makes social media platforms a vital space for reaching new people and growing the museum's community through cultural dialogue.

For a museum’s social media to actually work, it needs a clear plan. Kidd [32] argues that museums must move beyond simply broadcasting information, which is nothing more than a one-way announcement, and instead start encouraging people to participate. This means focusing on conversations and real interactions. Without a strategy for this kind of interaction, a museum's social media pages end up as static digital billboards, wasting the platform's potential to build a community [33].

A well-planned social media strategy allows museums to target specific groups and build real relationships with them. Castro [31] points out that instead of just posting generally, museums are now reshaping audience engagement by moving toward personalised communication that appeals to diverse visitor motivations. This kind of strategy is vital for museums like Boijmans Van Beuningen; it ensures that every interaction is aligned with the museum’s goals and audience growth [33].

A major reason museums use social media is the need to reach younger audiences. Parker [32] explains that since the pandemic, museum strategies have clearly focused on reaching new generations. These platforms are perfect as they offer innovative ways for connecting with younger people who want fast-paced content that is easy to access, visual, and interactive. To connect with these groups effectively, museums need to be quick and responsive, encouraging followers to actually participate in the conversation. By using social media for honest, two-way communication, museums can stay relevant to "digital natives" who grew up online [32]. Ultimately, by matching the language, style, and speed of apps like Instagram and TikTok, museums can keep people interested long after their physical visits.

To sum up, social media for museums is no longer a side activity; it is a strategic necessity. By leveraging social media platforms and treating their online pages as a place for real conversation, museums can grow their community, make their collections more accessible, and stay relevant for years to come [31, 32].

Social Events

Museums today are seen as places to have an experience, rather than just buildings where static historical objects are kept. To stay relevant, museums are focusing more on social value, recognizing that people want their visit to be just as engaging as a trip to the cinema or a theme park [38]. To meet these expectations, they are using social events and creative programming to build better connections with their visitors [41].

The clearest example of this shift is the rise of museum "Lates"—informal evening events designed to attract younger crowds. Research shows these programmes focus on engaging younger audiences, particularly Generation Y, who often seek social leisure activities with friends [39]. A study on London's Museum Lates [26] confirms that these events draw in a completely new audience who come for the social atmosphere rather than purely educational goals. By staying open late and blending cultural content with a relaxed atmosphere, museums are successfully turning themselves into popular social spots [39].

Besides just reaching younger people, social events are a great way to bring in a more diverse crowd. Programs such as "Nights at the Museum" mix art and science to help people understand complex subjects in a more relaxed way, while encouraging broader participation [40]. By hosting these informal events, museums can break down the traditional barriers that often make people feel unwelcome, making the institution more open to everyone [40].

In the end, social programs are essential for keeping museums relevant and successful in the long run [41]. These events serve two significant purposes: they help the museum reach more people and turn it into a lively hub where the local community can gather [41]. By prioritising the social side of a visit, museums become an integral part of the broader leisure economy, a place where people choose to spend their free time, ensuring a more diverse and active future for the institution.

Gamification

Gathering, preserving, and displaying artefacts has always been a museum's top priority, but in recent years, there has been a deliberate pivot toward a more visitor-centred approach [11]. Museums have consistently experimented with gamification and playful experiences in an effort to combat the waning interest seen particularly among younger audiences. Jenny Kidd, a museum scholar, describes this phenomenon as a "ludic turn," which emphasises the increasing understanding of play as essential to cultural engagement [15]. The strategic implementation of games within and about museum spaces has been shown to boost interest, facilitate informal education, and enhance visitors' positive perceptions of the institution [14]..

However, some scholars caution that an excessive emphasis on play carries the inherent risk of transforming museums into venues of pure amusement, raising valid concerns about the need to balance active participation with critical institutional values [15]. Karin Ryding discovered, for instance, that while treasure hunts and mystery games align with visitor-centred strategies, they are not intended to detach the gaming experience from the museum's core mission [11].

Interactive games and activities have been empirically proven to be successful methods for engaging audiences, promoting inquiry, destigmatising learning, and building closer bonds with visitors. These experiences allow visitors to feel a sense of adventure through approaches like content play and physical play, which reposition them as active participants rather than passive spectators.

HCI research has investigated numerous designs, ranging from isolated technology to hybrid physical-digital activities, contributing to the increasing use of technology in museum experiences [15]. While these approaches effectively promote engagement, they frequently fall short of connecting to deep historical contexts, often losing sight of the artworks' original cultural purpose. Visitors may find the activities enjoyable yet depart without fully comprehending the significance of the museum's main draws or their underlying narratives.

A significant portion of research is dedicated to finding the right balance between knowledge acquisition and genuine engagement. Beyond just attracting visitors, museums want people to reflect on, identify with, and appreciate the richness of their displays. While many existing projects show that games can capture interest, they often fail to meaningfully integrate the museum's content into the heart of the activity. This is where the 'serious game' concept offers a crucial advancement. Recent literature highlights that serious games are being developed to enhance education by embedding historical facts directly into the mechanics of play, ensuring the learning experience is both effective and memorable [44]. This approach supports a constructivist perspective, where game-based learning becomes an innovative way for visitors to actively build their own knowledge about exhibits [45].

Furthermore, the use of cutting-edge technology directly addresses the need for deeper context and immersion. Mobile serious games, for instance, are now being successfully deployed to enhance user experience by directly connecting game mechanics with cultural heritage content within the museum environment [43]. Pushing this immersive frontier even further, researchers are actively exploring VR and MR environments for gamified cultural immersion. Studies demonstrate that these tools create emotionally rich experiences, allowing visitors to engage with city heritage in captivating new ways [30]. Similarly, immersive virtual exhibitions are transforming cultural heritage by offering compelling digital experiences that overcome the traditional, passive way of viewing art and history [42].

This problem is addressed in the game by building the puzzle mechanics around around the learning process itself. Instead of offering facts as optional extras, the game explicitly demands that players understand the artworks they are restoring. With each puzzle solved, the museum's art, history, and culture become clearer. By weaving information directly into every part of the game, the experience naturally stimulates curiosity, making exploration a direct path to deeper understanding. In this way, the project helps potential visitors appreciate the importance of cultural institutions while encouraging them to visit in person. Beyond just entertaining, it shows how participatory play can help people of all ages form lasting connections with art and history. The success of serious games and immersive technology provides a clear framework for this project; however, while their ability to encourage participation is well-proven, they still require careful testing to ensure they effectively communicate deeper cultural meaning.

Conclusion

Choosing to focus on gamification through serious games is an effective way to bridge the gap between pure entertainment and deep cultural learning—a challenge many studies have identified.

This project has made a creative use of serious games, which are programmes designed for more than just playing, because research shows they significantly enhance the visitor experience [27]. This strategy is more effective than simple interactivity because it centers the entire experience around clear learning goals. The reason this works is simple: when learning is the core mechanic of the game, the information becomes both accessible and memorable [27].

Furthermore, incorporating game mechanics allows the project to seamlessly integrate immersive technologies, strengthening visitor engagement. Recent studies on VR and MR show that gamifying these environments is a powerful way to deeply immerse people in culture [30]. This combination creates emotionally rich experiences that go far beyond traditional viewing. By structuring the puzzles as a game, the project supports this approach, putting the visitor at the center of the cultural narrative as an active participant [30].

Ultimately, the project’s decision to embed educational content right inside the puzzles, ensuring players must engage with the art to progress, is well-supported. It applies the principle that learning goals should drive the game design [27], while using immersive, emotional methods to ensure the cultural experience is both meaningful and memorable [30].

2.2 Virtual Reality & Digital Heritage Preservation

Immersive technologies offer compelling advantages for museums [5], opening up new possibilities for how visitors connect with art and culture. Through these interactive, stimulating environments, audiences can explore artworks and artefacts in ways that are far more engaging than traditional displays. Users can experience storytelling in real time, interact with objects, and walk through digitally simulated spaces, making it easier to develop a deeper understanding and emotional connection to cultural artefacts [1; 2]. Such experiences encourage users to enjoy the learning process rather than simply taking in information passively.

One of the most significant advantages of immersive technology is its ability to remove physical limitations. Museums are often constrained by space, budget, and staffing. These constraints limits how they display exhibits or how many visitors they can host at a time. Digital environments allow museums to share entire galleries, exhibitions, or historical scenes without the need for extra infrastructure or hiring staff for daily events, making their collections accessible to a much larger audience. This is particularly beneficial for smaller museums like the MHFF, which may lack the resources to build expansive or constantly updated physical exhibits [5]. In addition, advances in 3D digitisation make it possible to share artworks and artefacts with visitors around the world. Educational initiatives increasingly rely on immersive platforms to bring museum collections into homes and classrooms where access would otherwise be limited [4]. This not only expands the museum's reach but also allows people from diverse backgrounds to connect with cultural heritage in meaningful ways.

Despite these advantages, immersive technologies also come with their risks and challenges. A prominent concern is that digital simulations may reduce the authenticity/quality and personal connection that the audience experiences when standing in front of an original piece [1]. Many critics argue that mediated experiences can feel disconnected or superficial, lacking the emotional impact that physical presence can create. Furthermore, as artworks age or are recreated digitally, potential quality issues can lead users to question whether the reproduction truly captures the essence of the original [2].

Technical limitations add further complications to the picture. Consumer-grade headsets, designed for home entertainment rather than heavy public use, may not be durable or safe enough for continuous interaction in a museum setting. Issues like simulation sickness, hardware malfunctions, and maintenance challenges can hinder the overall experience [5]. Moreover, many existing VR museum applications fall into the trap of providing 360-degree video tours—essentially passive experiences where users look around but cannot engage meaningfully with the content [3]. While such implementations increase access, they often fail to create truly immersive or interactive learning opportunities.

Smaller museums like the MHFF face additional barriers, as high costs, a lack of technological expertise, and infrastructure limitations can prevent them from implementing advanced immersive solutions. Without tailored approaches, these museums risk falling behind in an era where audiences expect dynamic, interactive experiences.

2.3 Serious Games: Breaking the Ice

Serious games are defined as problem-solving tasks approached through a lens of play, where the core purpose transcends mere entertainment to prioritise education, training, and critical reflection [44]. This approach has sparked a "ludic turn" within the museum sector, evolving the institution's role from a one-way delivery of neutral information into a dynamic, multi-layered dialogue between the collection and its visitors [15]. By repositioning visitors as active co-creators rather than passive observers, these games encourage hands-on, experiential learning within genuine heritage settings [45]. Ultimately, this shift towards a "socially engaged museum" framework places greater emphasis on the narratives and social significance of exhibits, rather than just their aesthetic or visual appeal [16].

The e-Tracer AR Quiz acts as a UX amplifier, replacing traditional text-based quizzes with a scavenger-hunt style assessment. Visitors must physically locate artefacts, such as a silver pen-case, and answer by scanning the object with their camera for marker-based validation. The system uses Unity and ARCore to provide points, leaderboards, and difficulty levels tailored to user profiles [16]. While the Bring Your Own Device (BYOD) model reduces museum costs, the high processing power required for 3D AR content can exclude visitors with older smartphones. Additionally, whereas outdoor AR is a mature technology, indoor tracking remains sensitive, requiring visitors to stay within 1.5 metres of an artefact for stability [16].

Twitto is a role-playing hybrid experience where players progress through narrative chapters, transitioning from a partisan member to a state leader. Using "Artcodes", scannable markers disguised as historical insignia, players unlock tasks requiring creative or performative responses, such as photographing a museum artefact to include in a personalised "Wanted" poster [15]. The game faced "curatorial friction", as staff were concerned the playful tone might encourage visitors to mock the museum's serious mission. Technically, the system struggled with precision; while early physical stamps were replaced by digital codes, scanning remained sensitive to museum lighting and angles. Furthermore, some visitors experienced a "disconnect", where the playful role-playing elements occasionally distracted from deep historical reflection [15].

The National Museum of Roman Art Serious Game utilises high-fidelity 3D digitisation to transform static Roman artefacts into interactive assets. Moving beyond passive observation, players act as "active investigators", rotating high-resolution models to examine structural details and solving challenges that require the application of historical knowledge. The system leverages ICT to create fast-paced feedback loops, specifically designed to re-engage younger audiences who might otherwise find traditional archaeology unappealing [44]. The project requires a "triple-threat" of expertise in 3D modelling, archaeology, and pedagogy, making it financially and technically demanding for many institutions. Furthermore, achieving the correct balance between entertainment and education is difficult; if the "pedagogical role" is not clearly perceived, students may engage with it as a pure video game, failing to meet the intended historical learning objectives [44].

"Where is the postilion’s post horn?" is a multisensory scavenger hunt where visitors assist a historical figure in recovering lost equipment. To progress through museum floors, players solve riddles, listen to audio clues from a "medieval herald", and use holograms to find "hidden keys". As challenges are met, digital pieces of the horn "fall from the sky", allowing players to assemble the full object as a visual marker of their progress [45]. The game suffered from a management issue, where the child-centric design led adults to manage the device rather than engage with the content. Technical integration was hindered by the museum's thick-walled historical architecture, creating "dead zones" that required complex offline workarounds. Additionally, the game required a significant restructuring of the museum's layout logic to ensure the narrative direction felt like a cohesive "common thread" rather than a series of disconnected puzzles [45].

In contrast to the games previously discussed, The Missing Piece is designed as a dedicated icebreaker that systematically addresses the barriers identified in earlier research. While some projects require a "triple-threat" of specialised expertise and high-cost digital assets, The Missing Piece utilises a streamlined framework that can be easily integrated into existing museum infrastructure. This ensures a sustainable implementation for institutions with limited budgets and technological resources.

Furthermore, the game resolves the limitations of other games that require players to be physically present at the museum to participate; instead, our game is more accessible to potential visitors, with the goal of converting them into actual visitors. Unlike other museum games that are either cost-prohibitive or overly distracting, The Missing Piece acts as a purposeful "icebreaker". It is designed to be a tool that draws users closer to the museum’s core, rather than a distraction that keeps them focused solely on their screens. By requiring players to observe digital versions of real-life objects, the game ensures the collection remains the "star of the show", while its streamlined design makes it a practical choice for any institution.

2.4 Adapting Artworks & Narratives into Interactive Media

Studies on immersive experiences stress that human interaction is essential [3; 2]. It is vital not only for navigating the technology but also for making visitors feel truly engaged and connected. However, many current virtual museum projects fall short of this standard. Instead of letting visitors actively participate, they often function as simple, passive tours where visitors follow a fixed route, absorbing facts without the opportunity to explore or think critically.

Some projects, such as the Louvre's virtual exploration of the Mona Lisa [9], demonstrate that adding a narrative can strengthen a visitor's connection to the artwork. By providing historical and artistic context, these efforts make the overall experience richer. Still, they also uncover significant issues. Official digital reconstructions are often held back by strict rules of the museum, while unofficial, imaginative versions can be unreliable in their quality and accuracy. These inconsistencies lead people to question the reliability of the stories being told digitally.

Previous research confirms that strong narratives and human connection matter, yet it also points out that many digital experiences force users into passive watching or listening. This limitation is a significant drawback, especially for younger, tech-savvy audiences who expect real interaction, creativity, and emotional involvement. Without a compelling story and personal participation, these immersive experiences risk becoming superficial and unmemorable.

2.5 Amplifying Learning through Music Assistance

Music plays a key role in creating immersion, emotional engagement, and learning. In playful settings, children often interact with music unconsciously while focusing on the activity, yet these experiences are built on memory, emotional connection, and the way meaning is formed [48]. When music is integrated into the activity and make-believe, education tends to occur naturally through repetition, exploration, and emotional involvement, rather than through direct or explicit instruction.

Research on this medium shows that music can enhance attention, motivation, and information retention when it is experienced as part of a core activity rather than as an external element [49]. Music is most effective when it is integrated into a wider experience, helping players stay immersed and reinforcing learning through repeated exposure [51]. This perspective also reflects analyses of the "Mozart Effect," which suggest that extensive learning benefits come from active, contextual musical experiences rather than just listening alone [50].

For this thesis project, original background music was developed using AI specifically for the museum setting and for each artwork featured in the game. Every level uses music inspired by the elements and history of the corresponding artwork, helping players form a stronger emotional connection to both the space and its cultural context. During repeated playthroughs, the subtle impact of the lyrical elements within the music introduces factual details about the artworks. Over time, potential visitors begin to retain this information unconsciously, allowing learning to happen through immersion and engagement instead of blunt or forced educational prompts.

By using music as an integrated element rather than an upfront instructional tool, the game leverages research on music, play, and learning to support memory retention, emotional involvement, and exploratory learning within an interactive virtual platform experience.

3. METHODOLOGY

3.1 Research Approach

We have a powerful opportunity right now to enhance art education using digital tools. We frequently hear about the positive emotional impact of technology in museums [1; 4], but applying game-like, puzzle-based activities in small, local institutions is still an area in need of new ideas.

Most current research and the highest-profile digital projects are centered on large, famous museums [5; 8]. These places have huge budgets and dedicated staff, setting a high standard with complex VR exhibits and large multimedia setups. While these elaborate models confirm that technology successfully draws people in, they are also incredibly costly to build and maintain. We urgently need new solutions to democratize these benefits and make them accessible to everyone.

Local institutions, like the Museu Henrique e Francisco Franco (MHFF), operate with smaller budgets and minimal technical staff [18]. These mid-sized museums play a crucial role in safeguarding culture, and they deserve digital tools that are both effective and practical for their needs. Finding ways to integrate game-based learning smoothly into their visitor experience is critical. Developing these resources gives us a huge, exciting opportunity to connect more deeply with the community and capture younger, tech-savvy audiences [14].

To make this possible and to ensure learning materials can be used widely without causing problems, we must look at designs that are flexible, scalable, and easy to implement [13]. This study supports a new path by focusing on a fundamental, low-cost puzzle game design.

The main goal is to show clearly that by choosing these smart, powerful, and simple methods, even smaller museums can fully realize the huge educational and visitor benefits of digital games. This focus on practical innovation creates a new approach to cultural education that is durable, adaptable, and equitable for the entire museum world [15].

3.2 About the Museum

Figure 1: Museum of Henrique e Francisco Franco [24].

The physical location for this dissertation is the Museu Henrique e Francisco Franco (Figure 1). The actual history of this museum reveals how cultural goals have changed in Madeira over time. The commitment to preserving the Franco brothers' artwork began informally during the 1940s and 1950s. At that time, the sculptor Francisco Franco and his family moved many of his large plaster works to the Museu José Malhoa because they lacked sufficient storage space.

However, the plan to build a museum dedicated solely to them only came to fruition later. Following the deaths of Francisco in 1955 and the painter Henrique Franco in 1961, the Funchal Municipal Council began purchasing the rest of their art with the official intent of creating a dedicated museum. The building process took decades to complete. This delay was primarily

due to two major issues: first, regional cultural leaders preferred older, more traditional art, meaning the modernist Franco collection was not a priority.

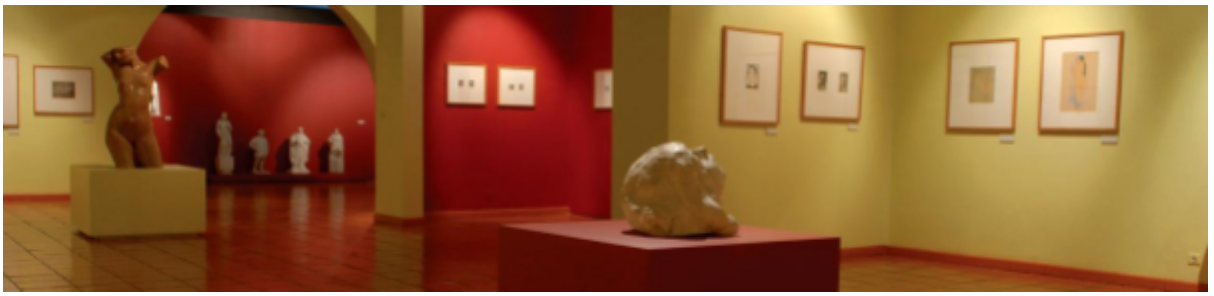

Figure 2: Inside of Museum of Henrique e Francisco Franco [25].

Second, the Council's ownership of the art, rather than the more powerful Junta Geral, created political tensions that halted development. Consequently, the Franco collection was first kept safe inside the Museu da Quinta das Cruzes. The project received significant support after the 1974 Carnation Revolution. Following public events that showcased the stored works, the Council decided to restore the nearby, empty Maternal-Infant Dispensary (built in 1940), a structure that matched the style of the brothers' most creative period. After the building was renovated to create separate areas for Francisco's sculptures and Henrique's paintings, and after more key artworks were purchased from the family, the Museu Henrique e Francisco Franco in figure 2, finally opened its doors on August 21, 1987. The museum has since continued to expand, notably by acquiring more of Francisco Franco’s drawings in 2008 [24].

3.3 Collaboration with the Museum

The project began with our direct collaboration with the Museu Henrique e Francisco Franco. This key museum is fully focused on both preserving its historical art and enhancing cultural learning in Madeira. From the very beginning, our approach was carefully designed to look beyond simple research questions and address the real, everyday needs of the museum and its visitors..

The museum’s involvement was essential. Staff didn’t just provide digital photos; they shared detailed expert knowledge about the history and meaning of the Franco brothers’ artworks. Importantly, the mananagement team clearly discussed their main goals, which guided the game’s final design and its educational purpose. This expert advice was crucial, ensuring that our search for new ways to engage visitors stayed completely focused on the museum’s core mission.

This deep teamwork didn’t just help the research; it confirmed the project’s cultural value by solving a genuine problem for the museum. This meant our work created a useful, practical answer to their teaching needs, instead of just being a university project. This strong link to their mission greatly improves the prototype’s chances for long-term use and, crucially, its ability to be replicated as a guide for many other smaller museums dealing with the same issues of adopting digital tools and attracting visitors.

4. METHOD

4.1 Design

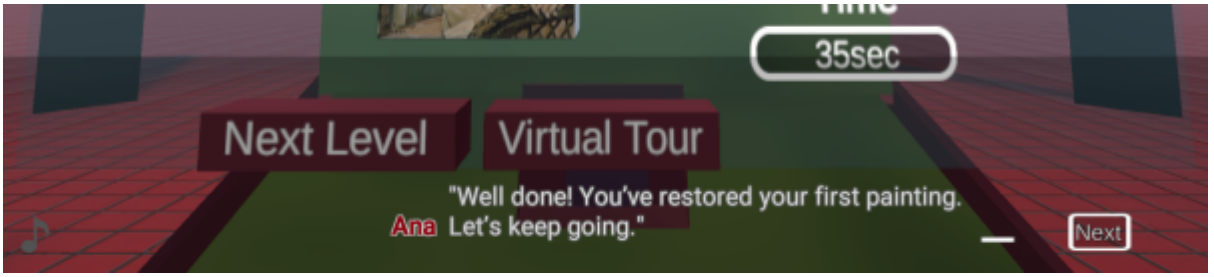

Figure 3: In-game text box of the Digital Guide.

Concept

The core concept centers on the player taking the role of a digital art restorer. By interacting with fragmented 3D interpretations of the museum's actual paintings and sculptures, players physically engage with cultural heritage to "repair" it.

The virtual curator, Ana (figure 3), is the main guide and friend for players throughout the game. Her presence is carefully built to make people feel supported and interested, which makes the whole experience easier and more fun, especially for younger players or anyone new to digital puzzle games. She talks in a friendly, conversational voice, offering gentle hints, explaining things, and giving encouragement without ever just giving away the answers.
Ana changes her help based on how the player is doing. For example, if a player is struggling with a hard puzzle, she gives subtle nudges or visual ideas to help them think hard and look for possible answers. But when players make a breakthrough or finish a task well, Ana recognises their success, boosting their feeling of achievement and pushing them to keep exploring.

By making Ana both a narrator and a practical guide, the game creates an immersive place for learning. Players aren't just messing with silent puzzles—they are having an active chat with the program, which sparks curiosity, reduces the chances of getting frustrated, and encourages trying new things. This design choice doesn't just improve the learning goals of the game; it also strengthens the connection between the player and the virtual museum, making the experience memorable and emotionally engaging.

Gameplay Structure

The Missing Piece is built around two areas that work together with the workshop, and each has a specific job in helping players learn and explore. The workshop is the practice room. It's a structured space where players pick up the skills needed for the puzzles, try out new game moves, and build confidence through guided tasks that get harder bit by bit. The museum, however, is the place for discovery and reflection. It lets players interact with and truly appreciate the artworks they've restored, learning important historical and cultural facts about each piece. Together, these two spaces create a complete gameplay experience that successfully balances learning skills with deep, meaningful exploration.

Figure 4: The Game loop chart.

Core game loop *(Figure 4)***:**

- **Enter a Level:**
  Players begin in a museum-themed level inspired by one of the museum's galleries.
- **Complete the Artwork Puzzle:**
  A 3D interpretation of a painting or sculpture appears in a disassembled form. Puzzle pieces spawn in a nearby slot, and the player must quickly and accurately place them into the correct position.
- **Timed Challenge:**
  The puzzle must be solved as fast as possible. Time and accuracy determine the final score, with a reward system (e.g., unlocking the paintings).
- **Go to Exploration Mode:**
  Upon solving the puzzle, players can free-roam to the digital museum space, where they can explore the now-restored artwork in a gallery setting.

- **Progression:**
  Each completed artwork is added to the museum’s collection. The player's mission is to restore all of the museum’s pieces by solving puzzles and unlocking the full museum experience.

Workshop

The workshop is the safe, main spot where you go from being a beginner to knowing your stuff. This area teaches you the basic moves for putting art back together: how to turn pieces, move them into place, and handle the 3D sculptures. It's built to be super supportive—a place where you can mess up and try different ideas without any pressure. Visual hints, helpful tips from the curator Ana, and simple demonstrations make sure you instantly "get" the logic of the puzzles. By moving through tasks that start easy and gradually get tougher, you steadily build the confidence and cleverness you need before you step into the main museum.

Museum

The museum is the big payoff—the moment you see what all your effort was for. This is where the fully restored artworks are finally revealed and explored in a setting that feels rich with story. You get to walk up to and interact with the finished pieces, instantly learning cool details about the artist, the history, and why the art is important. This space is all about exploring and thinking, letting you see the direct, satisfying result of the work you did in the workshop. Every piece you complete unlocks new parts of the museum, giving you a strong feeling of moving forward and achieving something. By mixing interactive fun with real history, the museum stops being a dusty old building and becomes a living place that perfectly blends gaming with cultural learning.

By breaking The Missing Piece into two clear areas, the workshop and the museum, the game successfully separates learning skills from exploring art. This provides a straightforward, adaptable plan for any educational museum experience. The workshop lets players practise the puzzle tools in a supportive, guided space, slowly getting harder to build their confidence and problem-solving abilities. When players finally move to the museum, they are rewarded with interactive, fully restored artworks, gaining both a beautiful sight and real educational insight into the history and culture of each piece.

This two-part design does more than just boost motivation; it shows a replicable approach for adding game-based learning into other cultural institutions. By carefully balancing preparation with meaningful discovery, the game ensures players get a complete, engaging experience that celebrates their accomplishments while truly deepening their understanding of art and history.

Puzzle

For all the levels' pieces may look different, they are actually identically shaped into cubes, so the player experiments with various pieces while focusing on the complete look of the artwork. This makes it easier for the guiding system to help when enabled at a later stage of the level. This style of puzzles promotes creating different levels of complexity easily, which makes the game scalable and adaptable according to the artworks available in the museum, making each level unique. Adding the random spawning system keeps it fair and leaves scope for replayability to improve score and timing. [20]

The puzzle mechanics are carefully designed to be both engaging and educational, offering players a hands-on experience with the artworks they are restoring. At its core, the gameplay involves manipulating puzzle pieces in the following ways: dragging and dropping, switching positions, rotating, and flipping pieces within a 3D environment. Each of these interactions is designed to reinforce spatial reasoning, pattern recognition, and problem-solving skills. The game gradually introduces these mechanics to avoid overwhelming players.

Early puzzles focus on basic placement, helping users familiarise themselves with the controls and the concept of assembling a fragmented artwork. As players progress, puzzles increase in complexity, requiring more advanced manipulation, such as precise rotation or flipping of pieces to match the artwork's intended orientation. This gradual escalation ensures that players continuously develop their skills while maintaining a sense of accomplishment.

3D interactions, in particular, allow players to engage with sculptures and multi-dimensional pieces, providing a more immersive experience than traditional 2D puzzles. By rotating objects or inspecting them from different angles, players gain a deeper understanding of the form and structure of the artwork, which also encourages curiosity and exploration.

Throughout the puzzles, subtle guidance from the AI curator Ana—through hints, visual cues, or gentle encouragement—ensures players remain motivated without feeling frustrated. This balance between challenge and support fosters a learning environment where players build confidence, develop critical thinking, and enjoy the satisfaction of gradually mastering increasingly complex puzzles.

Tutorial Design

The tutorial is carefully structured to introduce players to the game's mechanics in a gradual and accessible way. New interactions, such as dragging, rotating, flipping, or switching puzzle pieces, are presented step by step, ensuring that players can understand and practise each mechanic before moving on to more complex challenges.

Visual aids play a key role in the tutorial design. Highlighted pieces, arrows, animations, and subtle on-screen prompts guide players through each action, reinforcing learning without interrupting the flow of gameplay. The AI curator Ana complements these visual aids with friendly, context-sensitive instructions and encouragement, providing verbal guidance that adapts to the player's pace and performance.

As players progress, the tutorial seamlessly transitions into more complex puzzles that combine multiple mechanics. This gradual increase in difficulty ensures that players remain engaged and challenged while avoiding feelings of frustration or confusion. By scaffolding learning in this way, the tutorial not only teaches the technical skills required to complete puzzles but also fosters critical thinking, problem-solving, and curiosity.

Ultimately, the tutorial serves as both an educational and experiential bridge between the workshop and the museum, preparing players to confidently explore and restore artworks while enjoying a sense of achievement and discovery.

Personas

The personas for Sofia, Miguel, and Helena were developed by combining museum feedback with academic research on visitor behaviour. When consulting with the Museu Henrique e Francisco Franco, it became clear that they lacked detailed data on their audience because they primarily host organised school trips. Consequently, archetypal personas were created to represent "potential" visitors rather than current ones. In the process of designing the game, the age range of the visitors was considered, and based on that and the research, the following personas were created to keep the reach of the game broad.

The design of Sofia as a digital native is informed by the Audience Research Project Report by the ReReeti Foundation, which details how younger demographics prioritise visual and interactive multimedia over traditional text-based interpretation. The report's findings on how different age groups, students versus seniors, engage with digital media like Instagram and WhatsApp provided the empirical basis for the game's interface and communication style. By synthesising the institutional observations of the MHFF with these academic references, the personas serve as a robust foundation for the game's design, ensuring it functions as an effective icebreaker for a diverse range of potential visitors [54].

Figure 5: AI-generated image of persona “Sofia”.

1. **Sofia** - The Student

Age: 16

Occupation: School student

Marital Status: Single

Profile: Digital native, plays mobile games casually, curious but sometimes impatient.

About: Sofia loves art and culture and follows a lot of similar topic-based pages, influencers, and streaming events on Instagram, TikTok, and Twitch. She lives in a remote location in the countryside where there are very few small museums, and she has been there multiple times. Although those museums are full of beautiful artworks, it has become boring, and she doesn't see any value in going back for a few changes. She wants to travel and discover more museums and other art and culture institutions. She wishes her school could have programmes that could give her exposure to similar institutions.

Needs & Goals: Wants exposure to art and culture to be fun and not feel like “schoolwork”. Prefers short, accessible sessions.

Challenges: May lose interest if the content is too much or if the progression is too slow.

The persona of Miguel as a social learner is supported by the research of Coffee, who frames museum use as a social practice where visitors act as social actors rather than passive recipients of information. This perspective justifies the use of a 3D puzzle as a tool for shared inquiry and engagement, transforming the solitary act of viewing art into a collaborative or social experience [52].

Figure 6: AI-generated image of persona “Miguel”.

2. **Miguel** - The Young Professional

Age: 27

Occupation: Employee

Marital Status: Married

Profile: Time-conscious, moderate gamer, values clarity and smooth flow in apps/tools. Reported that some mechanics felt inconsistent or required extra effort.
About: A busy worker who wants to take some time out from his schedule and spend it with family and friends in fun activities. He has been invited to check a local small museum for an event, and he is unsure if this event of walking around and looking at artworks is a good use of his time.

Needs & Goals: Wants a polished, reliable experience. Appreciates quality and prefers smooth progression.

Challenges: Gets frustrated when educational content is forced into activities, making it boring and jarring.

The categorisation of Helena as a culture enthusiast aligns with Kurbanov's study of consumer behaviour, which provides a framework for segmenting audiences based on socio-demographic factors and personal motives, specifically the satisfaction of aesthetic and educational needs. By identifying these value orientations, the project could tailor game mechanics that satisfy the intellectual curiosity of frequent museum-goers while maintaining accessibility [53].

Figure 7: AI-generated image of persona "Helena".

3. **Helena -** The Cultural Enthusiast

Age: 45

Occupation: School Teacher

Marital Status: Married

Profile: Visits museums regularly, values heritage and cultural preservation, is not a frequent gamer, but is curious about new educational tools.

About: A schoolteacher who wants her students to appreciate art and culture. While teaching it in class, she has trouble explaining the artworks to most of the students, and when taken to multiple small and medium-sized museums, it becomes hard for her to maintain most of the students' attention.

Needs & Goals: Wants a meaningful cultural connection, not just entertainment. Enjoys contextual information about artworks while solving puzzles. Appreciates that the digital experience complements, not replaces, real museum visits.

Challenges: May feel overwhelmed if activities/games are too complex or have too many elements. prefers calm, simple, and reflective interaction.

After going through the brainstorming with the influence of the personas, it was concluded that even when the initial idea was inspired to engage students in museums, the potential of the game does not end there. There are plenty of different variations of visitors that can be targeted through this activity. New technology has created exposure of games towards the whole world.

So if a simple and easily accessible game welcomes a noninterested audience and creates even a point one percent curiosity in them towards the museum, it can easily increase the number of visitors to the museum and may have the potential to make the art and culture viral across the world.

Style Choices

The visual style of The Missing Piece was carefully chosen to balance simplicity with elegance, creating an environment that is both approachable and visually appealing. Instead of aiming for photorealism, which could potentially distract players from the educational goals, the design emphasises clear shapes, defined edges, and carefully selected colour palettes.

This approach ensures that puzzle elements, interactive objects, and artwork details are easy to identify and interact with, reducing cognitive load while maintaining immersion.
Colours and lighting were used strategically to guide attention and reinforce learning. Key interactive elements are highlighted through subtle contrasts, while the backgrounds remain understated to preserve focus on the artworks themselves. Similarly, textures and shading were simplified without sacrificing a sense of depth, allowing players to understand the form of sculptures and paintings without unnecessary visual noise.

This stylistic approach also supports the overall narrative and educational objectives. By prioritising clarity and readability over photorealistic detail, players can concentrate on puzzle-solving and exploring the museum environment while still appreciating the cultural and artistic value of the pieces. The result is a clean, elegant aesthetic that reinforces learning, encourages engagement, and provides a cohesive visual identity that resonates with both younger audiences and museum visitors.

Background Music

In the game, the background music is an element designed to increase immersion and support the game's educational goals. Rather than being a repetitive loop, the audio is dynamic; when a player plays a specific level or interacts with a restored artwork in the digital museum to learn more about it, the music shifts to a specific theme related to that specific piece of art. This helps create a unique atmosphere for each work and reinforces the connection between the player and the cultural heritage. Each Theme song has AI-generated music and lyrics specifically on the topic, for example default theme is on the history of the Museum -

English Version-
In Foonchaal's streets, you will see their craft,
Brothers' hands that shaped the past.
Francisco carved with strength and grace,
Stone and bronze found their place.
Henrique brushed with a gentle tone,
His colors are deep, his style his own.
Each told a story, pure and wide,
Of life and art, and what's inside.

They shaped the soul, they painted time,
In every line, in every rhyme.
Through form and light, through shade and hue,
They shared the world they deeply knew.
Not just a craft, but voice and flame—
Their art still speaks, still calls their name.

Their works were stored so far away,
No space at home for them to stay.
Decades passed, but hearts held tight,
Until the time at last was right.
An old clinic, quiet and bare,
Was turned into a place of care.
One side held stone, so firm, refined,
The other filled with painted mind.

They shaped the soul, they painted time,
In every line, in every rhyme.
Through form and light, through shade and hue,
They shared the world they deeply knew.
Not just a craft, but voice and flame—
Their art still speaks, still calls their name.

Francisco's hands gave shape to clay,
Busts and forms that still hold sway.
Henrique's brush lit canvas skies,
With peaceful depth and thoughtful eyes.
The museum opened in '87,
A gift of art, a touch of heaven.
With sketches, oils, and works once lost,

Portuguese Version-
Nas ruas do Funchal, verás seu fazer,
Mãos de irmãos a moldar o ser.
Francisco esculpia com força e graça,
Pedra e bronze em perfeita praça.

Henrique pintava com tom gentil,
Cores profundas, estilo sutil.
Cada obra conta uma história inteira,
De vida, arte e alma verdadeira.

Eles moldaram a alma, pintaram o tempo,
Em cada linha, em cada intento.
Por forma e luz, sombra e cor,
Revelaram o mundo em seu amor.

Não só ofício, mas voz e chama —
Sua arte ainda chama pelo nome da fama.

Suas obras guardadas, longe do lar,
Sem espaço para ali ficar.
Décadas passaram, mas o amor resistiu,
Até que o tempo chegou e enfim floresceu.

Uma clínica antiga, calma, vazia,
Virou lugar de arte e poesia.
De um lado, a pedra firme e fina,
Do outro, a mente pintada que fascina.

Eles moldaram a alma, pintaram o tempo,
Em cada linha, em cada intento.
Por forma e luz, sombra e cor,
Revelaram o mundo em seu amor.

Não só ofício, mas voz e chama —
Sua arte ainda chama pelo nome da fama.

As mãos de Francisco deram forma ao barro,
Bustos e figuras que resistem ao tempo raro.
O pincel de Henrique iluminou o céu,

Now found again, no matter the cost. A family's gift, a city's will, A space where time stands calm and still. And though the artists now are gone, Their vision, voice, and soul live on. They shaped the soul, they painted time, In every line, in every rhyme. Through form and light, through shade and hue, They shared the world they deeply knew. Not just a craft, but voice and flame— Their art still speaks, still calls their name.	Com profundidade calma e olhar fiel. O museu abriu em oitenta e sete, Um presente de arte, um toque de afeto. Com desenhos, óleos e obras achadas, Que voltaram ao mundo, por mãos dedicadas. Presente da família, vontade da cidade, Um espaço onde o tempo tem outra verdade. E mesmo que os artistas tenham partido, Sua visão, voz e alma seguem vivo. Eles moldaram a alma, pintaram o tempo, Em cada linha, em cada intento. Por forma e luz, sombra e cor, Revelaram o mundo em seu amor. Não só ofício, mas voz e chama — Sua arte ainda chama pelo nome da fama.

Table 1: AI-generated Game theme song lyrics in English and Portuguese.

These song will carry facts of the topic in them and after repetitive listening the will unconsciously retain facts of about the museum or the artworks.

4.2 Implementation

Game Engine

The game was developed using the Unity [47] game engine, with the Game Creator 2 (GC2) [48] plugin, to create the simple puzzle logic and player interactions. This combination provided a more creative and easier approach for the designer in developing the game using visual scripting and leaving the C# code behind while making the high-fidelity prototype. The game had 2 scenes: the workshop and the virtual museum. The developer was using the Dialogue Extension of GC2 to create the AI curator. The rest of the mechanics of the puzzle and the first-person museum experience were created using the default GC2 plugin.

Game Creator 2

The package empowers you to build the game through a suite of intuitive, flexible tools that handle the heavy mathematical lifting so you can focus entirely on creativity. This solution features intelligent characters pre-loaded with advanced navigation and animation, a camera system for any perspective, and a task-list visual scripting engine that keeps your project organised and easy to manage. By integrating player progress tracking and save-game variables, it provides everything you need to transform complex development into a streamlined experience [55].

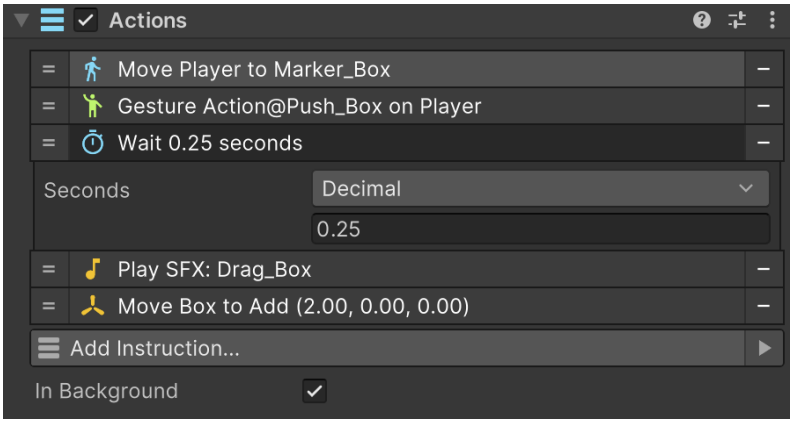

Figure 8: Actions execute instructions in top-to-bottom sequence where each task must complete before the next begins.[55]

The visual scripting toolset offers a high-level, intuitive approach to coding interactions using just three core components. Actions(figure 8) function as a sequential list of instructions [55].

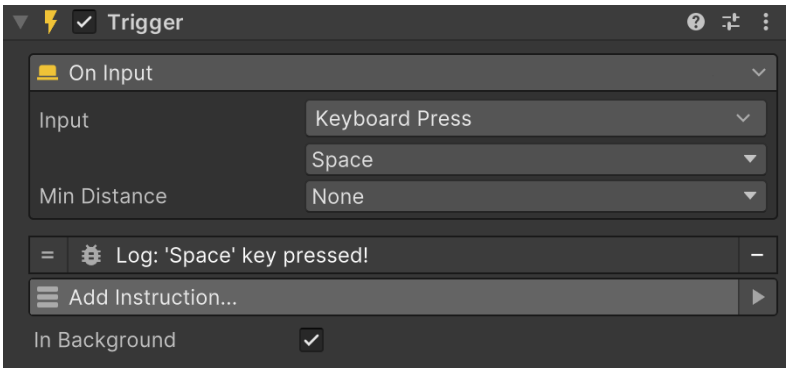

Figure 9: Triggers are components that monitor scene events and respond by firing a specific sequence of instructions.[55]

Triggers (figure 9) act as listeners for specific scene events, and Conditions (figure 10) allow you to branch your logic based on specific requirements. Within this hierarchy, the Actions component manages a list of individual instructions, while Conditions are organised into branches that evaluate specific states before executing commands. Meanwhile, the Trigger component remains dedicated to detecting environmental events. Beyond these functional logic tools, the package includes Hotspots, a specialised component designed to enhance player immersion by highlighting interactive objects through visual cues like character head-tracking or floating text prompts [55].

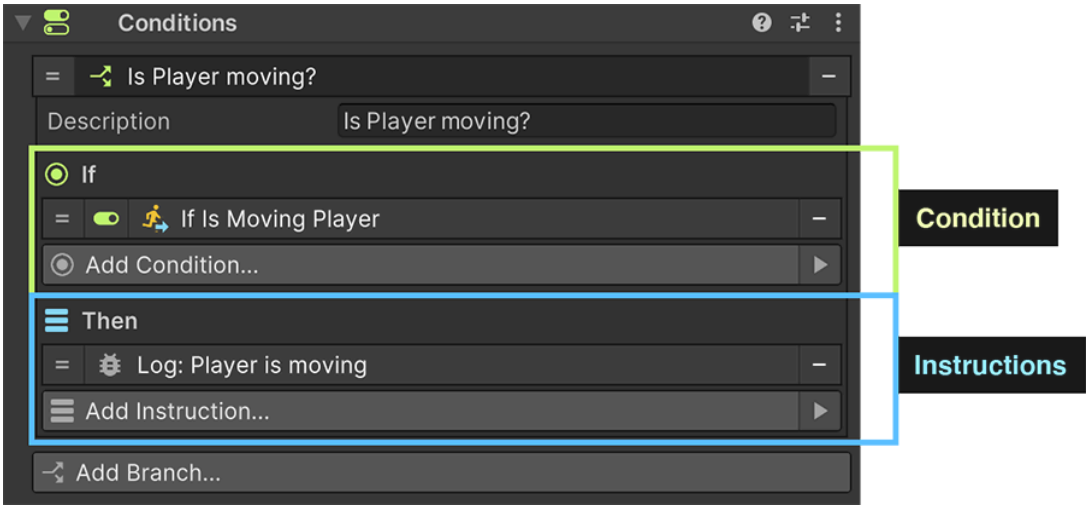

Figure 10 Conditions evaluate game object branches from top to bottom, executing the first set of instructions whose criteria are fully met before stopping.[55]

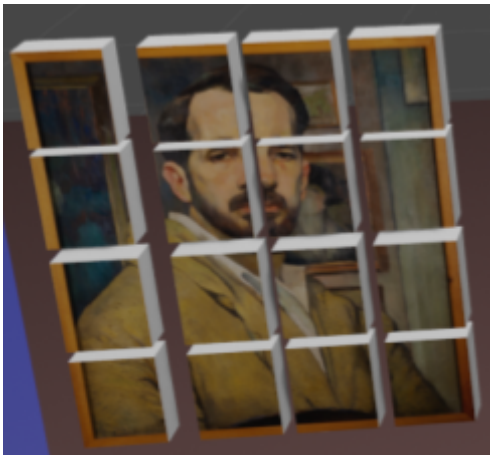

Figure 11: Dividing the artwork into small pieces(cubes) for the puzzle.

Puzzle mechanics implementation for prototype

The puzzle game development was distributed across multiple systems, which would include the spawner, grid, player input, player guide, tutorial, and more. Through the developer's research into optimising the game, it was decided that instead of spawning and destroying the puzzle pieces, the spawner would hide and reveal them. First, the pieces (Figure 11) and the texture were created in Blender and Photoshop; they were compiled in the engine, and all the pieces' materials were hidden and positioned out of the camera's range. An object array list was created for all the pieces to create a randomiser system to choose, reposition, and then reveal them at the spawner location to be picked up one by one until all the pieces have been used.

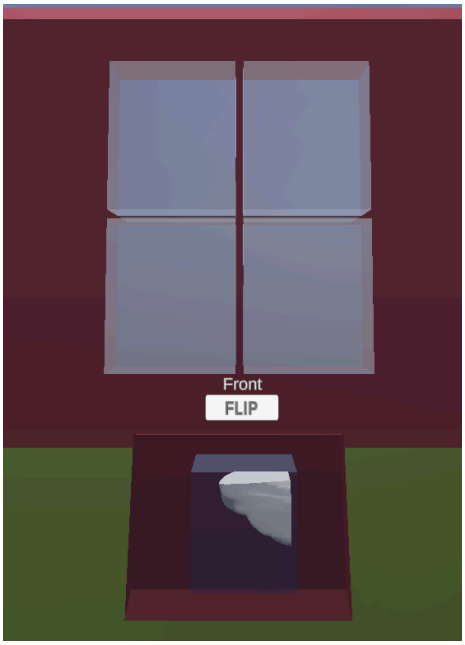

Figure 12: Spawn and Grid System layout.

After this, the platform where the picture will come together was developed. A block-based grid system (Figure 12) was created, and the number of blocks was determined based on the level's complexity. Each block contained triggers and variables; the triggers were there to check player input and the conditions of the variable, which would help the developer to enable other mechanics like switch, rotate, place, pick, guide system, and game end system.

Side by side, the player input system was also developing, and the environment was designed and created with VR in mind, so now, when the players navigate through the menu, level select, scoreboard, and the game level, it simulates a 90-degree head turn from one direction to another. Adding the pause menu, timer, and a placeholder settings menu to give better control for the player. These inputs later change WASD and mouse controls to navigate the 3D recreation of the museum to give a closer inspection of the unlocked artworks.

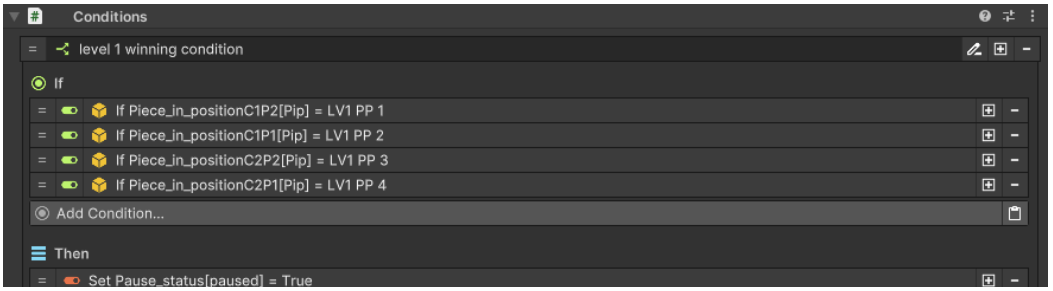

Figure 13: Level one winning conditions in the GC2 plugin format.

The automated systems of the player guide, tutorial, and endgame all contain conditions that check variables from the previous systems and activate the UI accordingly. For example, the Figure 13 image shows the winning condition of the level 1 puzzle of the game.

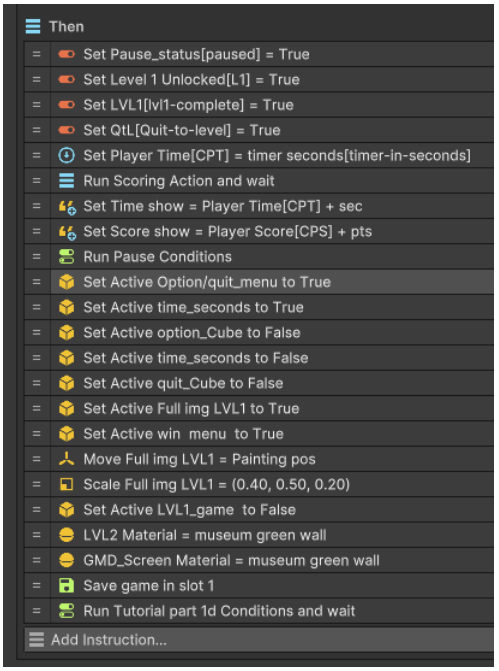

Figure 14: When level one conditions are met in the GC2 plugin format.

The figure 14 image shows what actions will happen when the player succeeds; this process was then templatised with the pieces and the grid system to create the other levels.

Artwork Digitization

Figure 15: The painting, bump map, and normal map
(devoloping the paintings in the Virtual Museum).

Currently, the game utilises high-quality images of paintings provided by the museum to represent the artworks within the game. These images allow players to explore and interact with the collection while maintaining visual fidelity close to the originals. To achieve a semi-realistic effect, a bump map and a normal map were applied to each painting, as shown in figure 15. For level four, we had to take pictures of the sculpture from all angles, and using them as references, a 3D model was created (figure 16), which was later also used to create the pieces of the puzzle. These processes would capture detailed textures, shapes, and spatial characteristics, enabling a more immersive and interactive experience.

By combining digitisation with optimised integration into the game environment, future versions of the game would allow players to examine and carefully observe the artworks in a way that closely mirrors interacting with physical museum pieces, thereby enhancing both educational value and engagement.

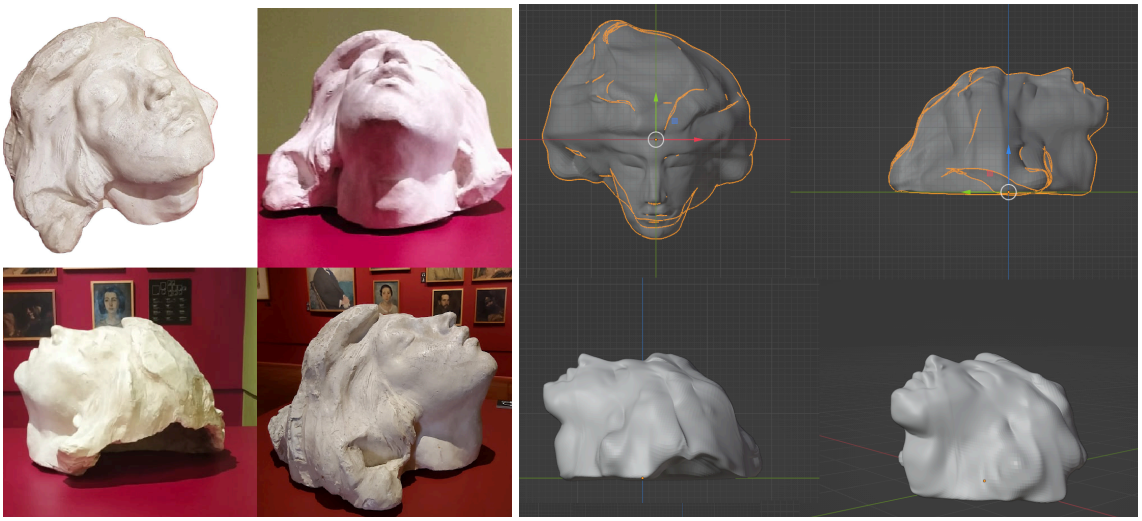

Figure 16: Sculpture reference and prototype 3D recreation.
(devoloping the sculpture in the Virtual Museum)

If the project progresses to the next phase of production, a dedicated team will undertake full 3D scanning and digitisation of all artworks.

In addition, the game's online implementation allows players to navigate the workshop and museum spaces naturally, interact with 3D sculptures from the comfort of their homes, and gain a sense of scale and presence that reinforces learning and exploration. The combination of high-quality visuals, interactive mechanics, and immersion provides a rich, engaging experience that brings the museum's collection to life in a virtual setting.

UI/UX Features

The user interface and experience in the game were designed with flow, simplicity, clarity, and accessibility in mind. Core interactions rely on intuitive mouse controls, enabling players to easily pick, rotate, flip, and place puzzle pieces. Clear visual indicators, such as an icon that appears in the corner of the screen while the cursor is hovering on the pieces to signal they can be rotated, help players understand possible actions easily.

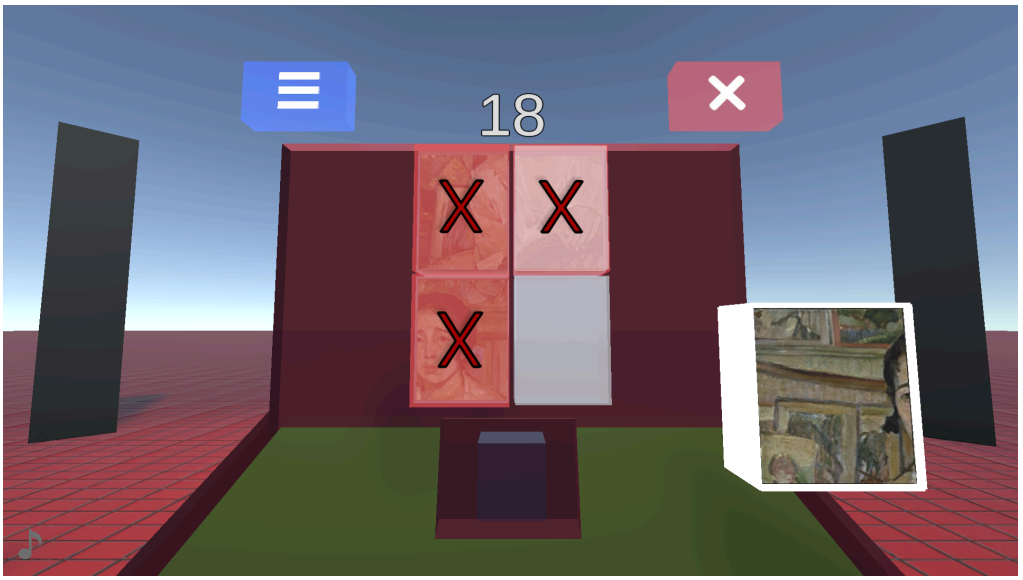

Figure 17: Wrong position visual indicator.(guiding system for the player)

The interface also includes a volume control, enabling players to adjust audio guidance and other sounds to their preference, which enhances comfort and accessibility. In addition, a contextual support system highlights incorrectly placed pieces (Figure 17), provided after a certain time bracket as visual feedback to encourage trial-and-error learning without disrupting the gameplay flow.

In the digital museum, interactivity is further enhanced. Players can hover over an artwork to highlight it, visually indicating that it can be explored. Clicking on the highlighted artwork reveals detailed information about the piece, including historical context, artist details, and cultural significance, and changes the background score to the theme of the artwork. This feature promotes engagement and educational exploration while maintaining intuitive navigation.

Complementing the visual cues, Ana—the digital curator—offers gentle, context-sensitive voice guidance. Her tutorial provides hints and encouragement throughout the player's gameplay without directly giving away solutions. The combination of clear visual feedback, supportive audio guidance, and interactive elements ensures a balanced user experience that fosters learning, reduces frustration, and enhances engagement throughout the gameplay space.

Virtual Museum Environment

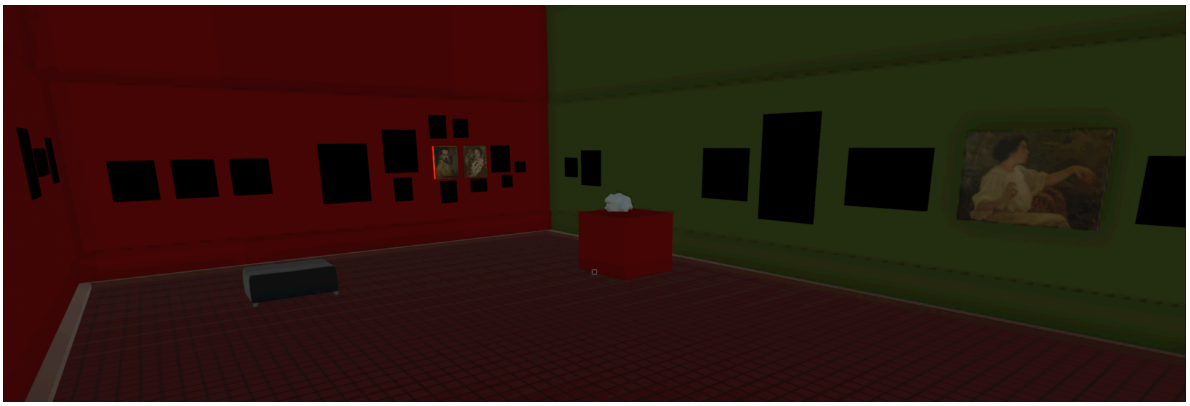

Figure 18: Indoor virtual museum view.

The Virtual Museum (Figure 18) serves as the culminating space where players can experience the results of their efforts in an interactive, immersive environment. As players complete puzzles in the workshop, individual artworks are unlocked and dynamically displayed in a virtual gallery, creating a tangible sense of progress and achievement.
The gallery is designed to encourage exploration and curiosity. Each unlocked piece can be examined up close, allowing players to appreciate details, textures, and compositions that mirror the original museum works. Interactive elements, such as hover highlights and clickable objects, provide additional information about the artwork, including historical context, artist background, and cultural significance. These features transform the museum into an educational space where players actively engage with art rather than passively observing it.

The Virtual Museum also reinforces motivation and reward. Unlocking artworks after solving puzzles creates a direct link between effort and achievement, encouraging continued engagement and experimentation with increasingly challenging puzzles. The immersive VR implementation further enhances this experience, giving players a sense of presence within the gallery and allowing them to navigate the space naturally. By combining visual fidelity, interactivity, and contextual learning, the Virtual Museum transforms the restoration process into a meaningful journey of discovery and cultural appreciation.

4.3 Evaluation Study

Study design

This section outlines the journey behind The Missing Piece, from its initial concept to its development, testing, and refinement, all aimed at creating an engaging, educational, and immersive experience for visitors to the MHFF. We approached this dissertation with the idea that the product, when thoughtfully designed, can transform the way people connect with cultural heritage. Our goal was not simply to build a game for fun but to create an experience that invites exploration, curiosity, and meaningful interaction with the museum's artworks disguised as a simple game.

To achieve this, our method combined thorough research, minimalistic design, and structured development. We began by studying existing research in virtual museum experiences, gamification/HCI and museum engagement, learning from both successes and shortcomings in the field. This foundation strengthens the idea behind the importance of contextual narrative design, emotional engagement, and intuitive mechanics, principles that guided every stage of the game's development.

We employed a mixed-methods approach combining the standardised SUS with a set of customised survey questions. The SUS provided a reliable measure of overall usability, allowing us to assess how easily players could navigate the interface, understand controls, and complete tasks within the game.

Participant recruitment

Participants for the evaluation were recruited from a variety of audiences to ensure a representative sample of museum visitors. This included school and university students, families with children, and general museum-goers with varying levels of familiarity with digital games and art. By involving participants with diverse backgrounds, ages, and experience levels, the study aimed to capture a wide range of feedback on usability, engagement, and educational impact.

Recruitment was conducted through both direct invitations and general online outreach, allowing visitors to voluntarily join the study and experience the game in a naturalistic setting. This approach ensured that the data collected reflected realistic user interactions and responses, providing insights that are meaningful for understanding how different audiences engage with the game. The diversity of participants also helped identify potential accessibility challenges, variations in learning outcomes, and areas where interface or tutorial design could be improved to accommodate a broader range of users.

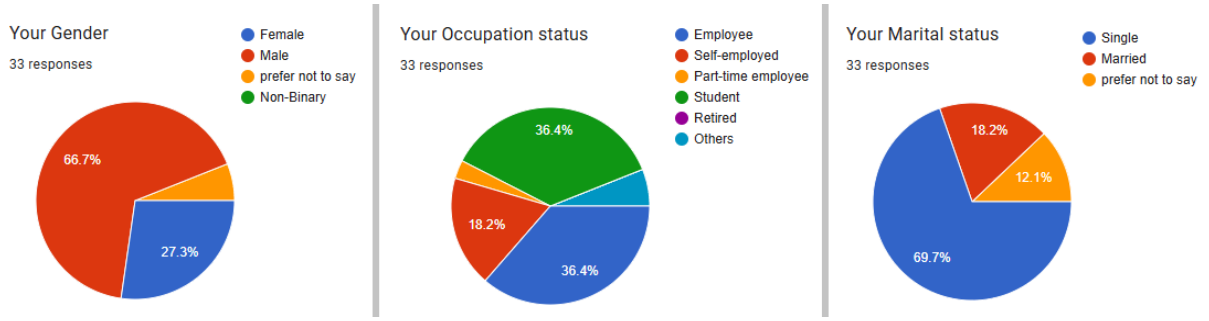

Figure 19: Charts on players' gender, occupation status and marital status percentage.

A total of 33 players participated in the survey, of which 22 were male, 9 were female, and 2 preferred not to say. Their occupational statuses were: 12 students, 12 employees, 6 self-employed, 2 others and 1 part-time employee (figure 19).

Our design process was thoughtful by nature, guiding tutorials, adjusting visual cues, and ensuring accessibility for players of all ages. We made it a priority to design enjoyable gameplay leading towards an educational depth, crafting puzzles that challenge without blunt attacks of cultural information dumps on the player and narratives that guide towards curiosity without distracting. Special attention was given to maintaining fidelity to the museum's artworks while using a simplified look that is approachable and compatible with available hardware, and at the same time, highlights the artworks.

User feedback played a role in the recognition of this process. We conducted playtesting with as many people as we could in the timeframe we had. In the survey, we added additional questions for all sorts of potential museum visitors to substitute for observing firsthand how players interacted with the game, and instead asked how many levels they were able to play, and if they discovered the virtual museum and knowledge check on the artworks they observed in the game.

Their excitement, hesitations, and creative solutions informed the gameplay, pacing, and interface potential. Structured surveys and attitude evaluations helped us measure how players' interest in the museum changed after engaging with the game, while open-ended responses provided nuanced insights into their emotional experiences.

Survey structure

1. Demographic & User Profile
    a. Purpose: To establish the "persona" of the player.
    b. Key Data: Age (Birthday), Nationality, Occupation, Marital Status, and Gender.
    c. Why it matters: Developers use this to see if the game appeals to their target audience (e.g., students vs. retirees) and if certain demographics struggle more with the controls.
2. Quantitative Usability (The SUS Model)
    a. The survey utilizes a modified System Usability Scale (SUS). This is a standard industry tool that uses "positive" and "negative" alternating statements to check for consistency in user feedback.
    b. Full Game Mechanics: Measures how "heavy" or "complex" the overall software feels.
    c. Puzzle Mechanics: Specifically focuses on the "micro-interactions"—the clicking, rotating, and switching involved in the gameplay.
3. Support Systems: Evaluates if the "scaffolding" (tutorials and visual cues like red highlights) actually helps the player or just gets in the way.
    a. Engagement & Pedagogy (Learning)
    b. Since this is a museum-based game, the survey measures "Edutainment" value:
    c. Curiosity: Did the art make the player want to see more?
    d. Observation: Did the puzzle mechanics force the player to look closer at the brushstrokes or textures?
    e. Reward Loop: Did the player feel a sense of satisfaction seeing the "restored" art appear in the gallery?
4. Knowledge Retention (The Quiz)- This section serves as a Learning Analytics check. By asking for the name, date, and medium of artworks across four levels, the developers can see:
    a. If the information was presented clearly enough to be remembered.
    b. Which artworks were the most "memorable" versus which were easily forgotten.
5. Qualitative Feedback (Open-Ended)
    a. Asking how you'd describe it to a friend reveals what the player thinks the game's "core identity" is.
    b. Identifying specific hurdles (like your feedback on the "statue puzzle" or the "interior quality").
    c. Allowing the user to suggest improvements (like your suggestion for "diegetic" assembly—building the art directly on the walls).

Measures

To assess the effectiveness of The Missing Piece, multiple measures were employed to capture both objective performance and subjective experiences. Participants' ability to complete assigned tasks, such as solving puzzles and navigating the workshop and museum spaces, served as a primary indicator of usability and comprehension. Task completion data provided insight into the intuitiveness of the controls, clarity of instructions, and overall accessibility of the game.

In addition to objective performance, participants were evaluated on subjective dimensions, including usability, enjoyment, and perceived learning outcomes. Standardised questionnaires, such as the SUS, quantified usability, while customised questions captured participants' engagement, satisfaction, and motivation. Knowledge retention was assessed by asking participants to recall information about the artworks, their historical context, and cultural significance after interacting with the game.

Open-ended questions complemented these structured measures, allowing participants to share personal experiences, suggestions, and observations. These qualitative responses provided rich, contextual insights into how players perceived the game, highlighting aspects that were particularly engaging, challenging, or educational. By combining task-based performance metrics with subjective and open-ended feedback, the study was able to provide a holistic evaluation of both the gameplay experience and the educational value of the game.

Due to the my relocation to India, in-person evaluations with the museum audience were not feasible, necessitating a change in measures to an entirely online assessment process. To mitigate the limitations of remote testing and effectively monitor player progression, a bespoke 'Knowledge Check' was integrated into the study. This section was specifically designed to ensure that information regarding the artworks could only be retrieved if the player successfully navigated the virtual museum, approached the artworks, and interacted with them directly. Consequently, the questions served a dual purpose: while some evaluated the depth of the participants' observation of the artworks, others acted as spatial verification to confirm that the player had reached specific locations to uncover the required answers. This structured approach allowed for a reliable reconstruction of the user's journey and engagement levels within the virtual environment despite the lack of physical supervision.

Protocol

During the study, participants completed a full play session before answering surveys. This ensured that players experienced both the workshop and museum environments and engaged with the full range of puzzle mechanics, interactive elements, and digital artworks.
To assess engagement and learning, knowledge-check questions were incorporated into the survey. These questions asked participants to recall specific details about the artworks they had encountered in the museum, providing a measure of how attentively they explored the environment and how effectively they absorbed the educational content.

By combining a complete playthrough with targeted knowledge-check questions and subjective survey items on usability and enjoyment, the study captured a comprehensive picture of player engagement, learning outcomes, and overall experience. This approach allowed the research to evaluate both the educational effectiveness and the interactive appeal of the game without relying on direct observation.

Through these approaches, we ensured that The Missing Piece not only meets the requirements of an easily approachable activity but also becomes a flexible conduit to represent and welcome any similar institution. The final experience is one where players feel like it's their choice to learn, explore, and emotionally connect with the artworks, while the museum benefits from a tool that encourages lifelong curiosity and appreciation for their cultural heritage.

User Research

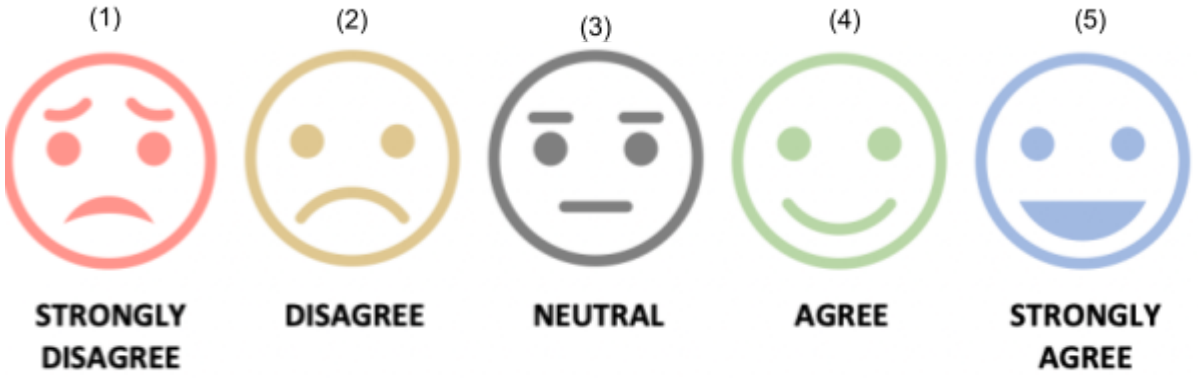

Figure 20: This shows what each number represents in all the survey options.

To understand how effectively The Missing Piece supports museum visitors in exploring, engaging with, and learning about artworks, we are using the System Usability Scale (Figure 20) as the primary tool for gathering feedback. The SUS is a widely recognised method for assessing usability, providing both structured and actionable insights into how users experience a product. The inquiries are following the format of choosing a numbers that align with the player's thought process from 1 to 5. This creates a spectrum from 1 being strongly disagreeing, to 5, which is strongly agreeing and 3, which is neutral or does not affect the user [23].

Our goal is to ensure that the game is not only easy to navigate but also enjoyable and educational, particularly for children and families who may be less familiar with museum settings or immersive technologies. At the same time, we aim to support museum staff by offering clear data on where the game succeeds and where improvements are needed, helping them refine the experience over time.

The evaluation is thoughtfully structured into several sections, each designed to explore a different aspect of the player's experience. These sections help us uncover how users feel while playing the game, how intuitive the controls and interactions are, how effectively the puzzles engage them, and whether the learning objectives are being met in a way that feels natural and rewarding. We also want to understand how players respond emotionally, whether they feel encouraged to explore more, how confident they are in solving puzzles, and if they feel a connection with the artworks presented.

By breaking down the evaluation into focused areas, we can gain a deeper understanding of how the game performs across different levels of interaction, from basic navigation to complex problem-solving. This allows us to identify patterns in user behaviour, preferences, and difficulties, ensuring that the final experience is aligned with the needs of diverse audiences. The feedback collected will guide adjustments to the game's mechanics, support systems, storytelling elements, and overall design, making the experience smoother, more accessible, and more meaningful for visitors.

Ultimately, the SUS framework offers a balance between quantitative data, such as ease of use ratings and time spent on tasks, and qualitative insights gathered from open-ended feedback. This combination enables us to continuously refine The Missing Piece, making it an evolving experience that grows with the needs of its users while helping museums create engaging, educational spaces that inspire curiosity, creativity, and a lifelong appreciation for art.

Full Game Usability (Part 1)

In this part, we want to understand how players feel about the overall experience. We ask questions like:

- "Would you like to play this game often?" (Figure 21)

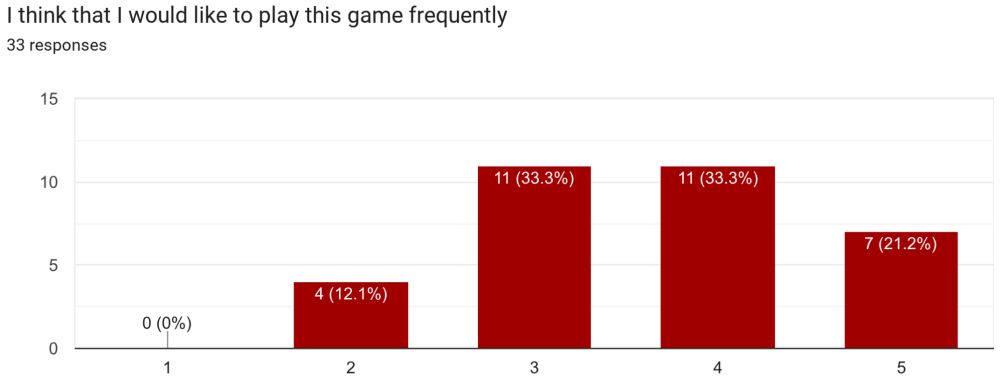

Figure 21: Google Form chart that is evaluating the players' interest in replaying the game.

- “Was it easy to get started?” (Figure 22)

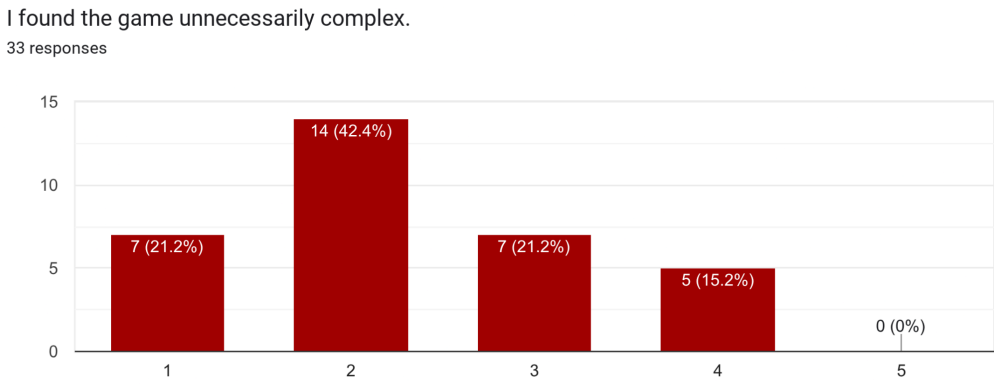

Figure 22: Google Form chart that is evaluating the players' finding the game complex.

- “Did you feel confident while playing?” (Figure 23)

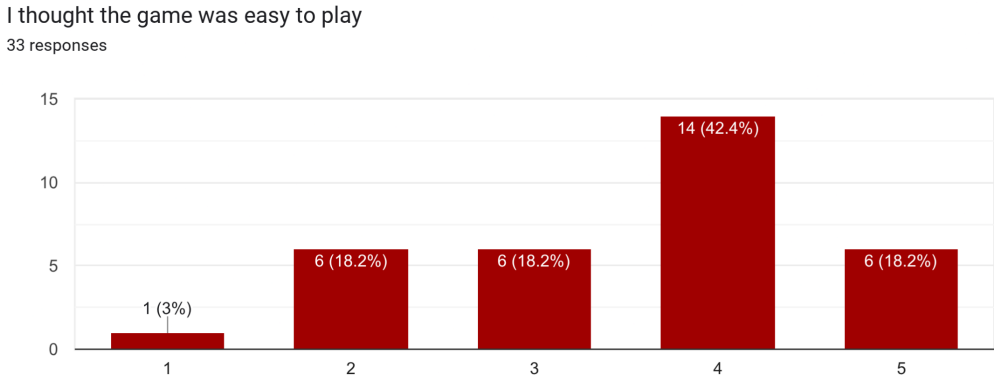

Figure 23: Google Form chart that is evaluating the players’ ease in playthrough.

These questions help us see how approachable the game is, whether the instructions and design are clear, and if the experience keeps players coming back for more. We also ask whether the game felt too complex or inconsistent; this helps us know where to simplify or guide players better.

Sus Results

The assessment of how easy the prototype was to use, which used the SUS, showed that people mostly thought positively of it. The average score for the whole SUS test was 71.74. This indicates that the system is good enough to be used, which is considered acceptable under SUS rules. The middle score (median) of 72.5 is just marginally higher than the average, indicating that a slight majority of users were happy with the system. The small standard error (2.45) is reassuring because it suggests the average score is trustworthy; if the test were repeated, the outcome would likely be very similar. However, the standard deviation (14.08) is quite large, showing that even though most people found the prototype straightforward and quick, many participants had a tough time with it, meaning individual experiences were highly varied, creating a scope for improvement in future iterations.

Puzzle Mechanics Usability (Part 2)

Here, we focus on how well players understand the puzzle itself. Can they figure out how to click, rotate, and switch pieces? Do the hints (like red highlights or tutorials) help when they are stuck?

We ask players:

- "Were the puzzle mechanics clear and easy to understand?" (Figure 24)

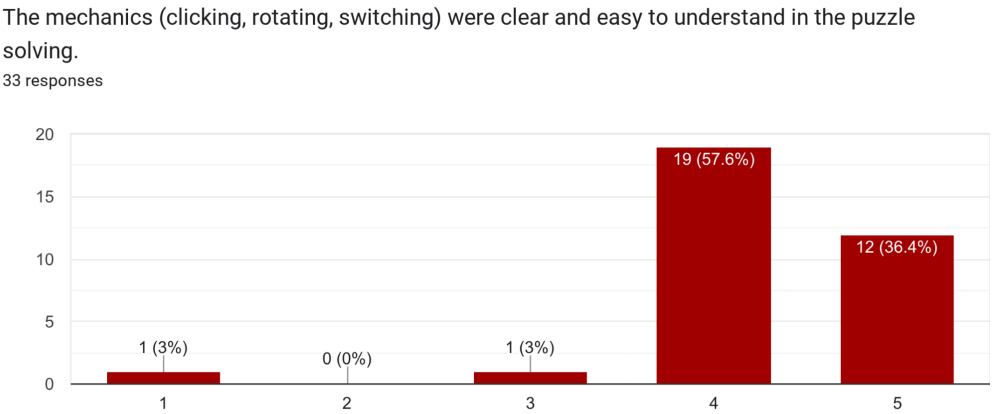

Figure 24: Google Form chart that is evaluating the players' understanding of the game mechanics.

- “Did the controls respond the way you expected?” (Figure 25)

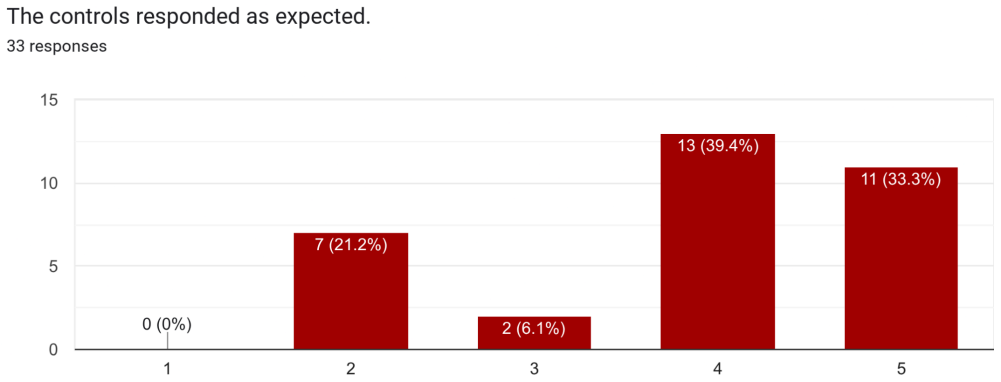

Figure 25: Google Form chart that is evaluating the players’ ease in controls.

- “Was it easy to follow the instructions?” (Figure 26)

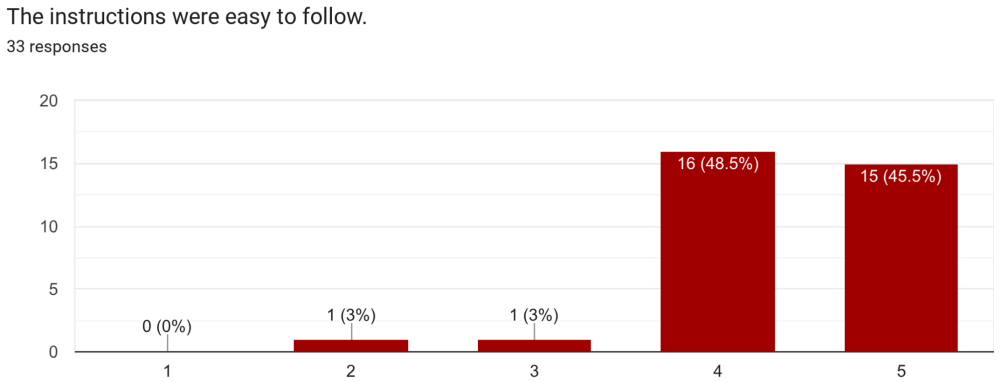

Figure 26: Google Form chart that is evaluating the players’ clarity of the instructions.

This helps us make sure that the way players solve puzzles feels natural and that the support systems are helpful rather than confusing.

Engagement & Learning

Learning should be fun! In this part, we ask players how the story, artwork, and puzzles kept them interested and how much they learnt from the experience.

We ask questions like:

- "Did the artworks and story make you want to explore more?" (Figure 27)

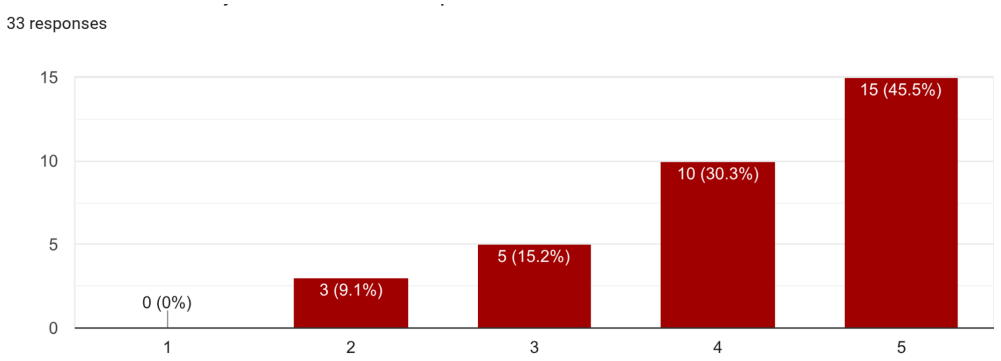

Figure 27: Google Formchart that is evaluating the players'want to explore more of the game.

- "Did you learn something new about the museum or the artists?" (Figure 28)

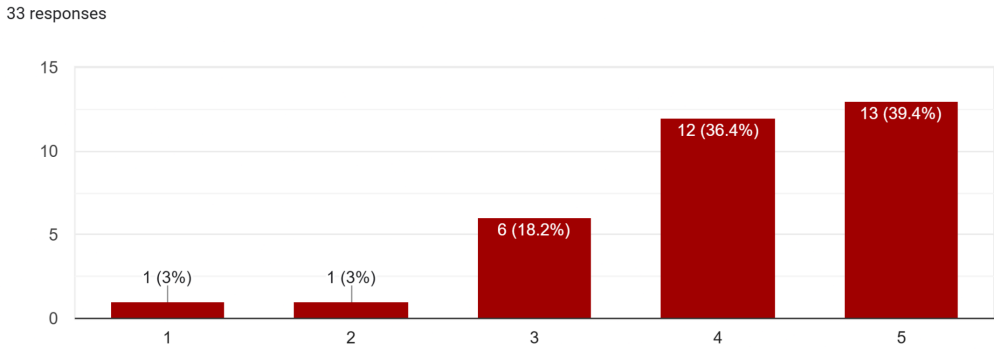

Figure 28: Google Form chart that is evaluating the players' new learnings of the museum.

- “Did the puzzles help you pay more attention to the art?” (Figure 29)

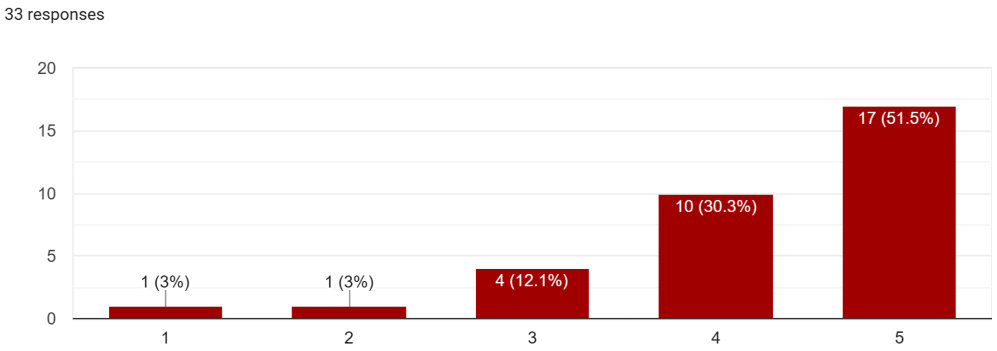

Figure 29: Google Form chart that is evaluating the players’ attention to details.

This helps us see how well the game inspires curiosity, attention, and a connection with the artworks.

Knowledge Check

We also want to test whether players actually learnt from the experience. For each level, we ask questions like:

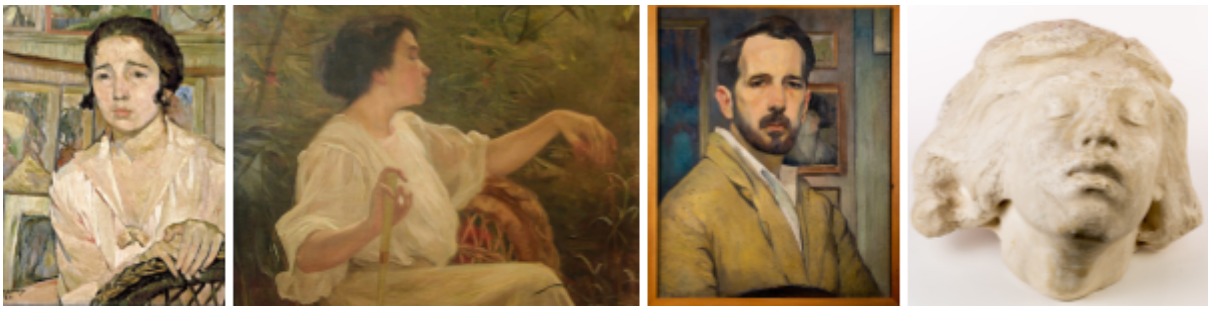

Figure 30: Artworks used for all the levels in the game.

- “What is the name of this artwork?”
- “When was it created?”
- “What materials were used?”

These questions help us measure if players are noticing and remembering key details of the artworks (Figure 30) while they roam the digital museum.

Open-Ended Feedback

Sometimes, players have great ideas that don't fit into fixed survey boxes. That's why we include open-ended questions where players can share what they liked most, what confused them, and what they would change to make the game even better.

We ask:

- "How would you describe the museum to a friend?"

  Quotes – *Participant-13:* "Small red museum packed with Portuguese art"; *Participant-20:* "Interesting to see for everybody who likes Portugal art, especial Modern." and *Participant-21:* "Interesting work in progress"

- "What did you like most about the experience?"

  Quotes – *Participant-1:* "Walking around the museum." *Participant-12*: "The music." *Participant-14:* "3D Part was tricky, I liked that."

- "Did you face any technical issues?"

  Quotes – *Participant-6:* "No, i didnt face any issues." *Participant-7:* "The instructions interfered with the gameplay, and mouse sensitivity should be configurable." and *Participant-21:* "Flipping was a bit unintuitive, and information bits were too much text so I often skipped them."

- "What would you add or change to improve the game?"

  Quotes – *Participant-1:* "Assemble the paintings inside the actual museum instead of the menu, and improve the quality of the interior." *Participant-6:* "I would add more levels to it with riddles to solve it further" and *Participant-16:* "Make the museum more realistic, close to the real structure",

This gives players the chance to express themselves and helps us make the experience more enjoyable and user-friendly.

Bringing It All Together

This framework serves as the primary mechanism for qualitative data collection. It enables an analysis that extends beyond technical functionality to understand both if the game is easy to use and how players actually feel about The Missing Piece. We blend strict rating questions with sections where people can just write what they think. The quantitative survey items, like those from the SUS survey, facilitate the assessment of fundamental usability metrics, such as ease of navigation and interface interaction. Can people solve the puzzles? Are the directions clear? But the open feedback sections are where the real insights are—players get to tell us about their emotions, thoughts, and advice in their own voice. Those are the important ideas that mere numbers can never truly show.

This approach means we aren't just checking off boxes like, "Yes, the buttons work." This allows for the investigation of more nuanced experiential factors, such as the participant's sense of inclusion and supported? Did the art make you curious enough to want to learn more? Did unclear instructions make you want to quit, or did you feel confident trying new tasks? Did the story make you feel connected to the museum? By asking these things, we figure out the human side of learning, making sure the experience supports both the brain and the heart.

The information we pull from this process will be the roadmap for the game's future. It'll tell us exactly how to fix the design, simplify the tutorials, set the perfect pace, and make the storytelling better. Our goal is simple: ensure players of every age can jump in and enjoy it without getting frustrated or confused. We want to build a space where everyone feels encouraged to explore. For kids seeing art for the first time, that means fun, easy challenges that spark pure wonder. For adults coming back to familiar pieces, it means giving them fresh, interactive ways to think a little deeper.

Ultimately, this feedback-first system is our guarantee that The Missing Piece is much more than just a puzzle game. It becomes a friendly, useful, and fun experience that fully supports the museum’s mission to inspire learning. By truly listening to our users and making the experience better based on their needs, we’re building a space where every single visitor feels capable, connected, and excited to discover the world of art.

4.4 Summary

The detailed, controlled method used in this research has successfully guided the creation of The Missing Piece. The outcome is a museum experience that feels rich and active, perfectly balancing education, fun, and ease of use. By combining testing with users, design improvements, solid technical work, and careful verification of results, this project demonstrates that digital tools can genuinely enhance a visitor's experience without compromising the true value or cultural significance of the museum’s collection.

Our method worked by mixing what people felt (qualitative data) with what the numbers showed (quantitative data) on the potential for development. This design of the puzzle tasks, the teaching guides, the digital recreations of the artwork, and even the use of virtual elements. Player comments will be one of the main drivers for making the game look better, improving the learning support, and refining the interactive parts. This ensures that players of all ages and skill levels can use the game easily and stay interested throughout.

The Missing Piece offers a usable framework that even smaller and mid-sized museums can adopt to boost how much visitors learn and engage. The unique two-part layout, which separates a workshop area for learning skills from the main museum for exploration, provides a structure that other institutions can easily use. This setup encourages people to be curious, think deeply, and truly interact with the art. This method ensures that virtual museum visits truly support learning, motivation, and an emotional bond with the artworks by combining fun, game-like features with content that is as historically and culturally relevant as possible.

Overall, this entire approach, built on understanding mechanics, comparative gameplay, and consistent game loops, clearly shows that games can add to museum visits, turning them into fun, worthwhile, and memorable experiences. It strongly highlights the importance of putting in the users' perspective. Attaching the game design within cultural settings helps to foster an extended interest in exploring and valuing art and heritage.

5. DISCUSSION

5.1 Puzzles

History: Picture puzzles, particularly rebus puzzles, which use pictures or symbols to represent words or sounds, have a long history. They originated using archaic symbols and phonetic systems, such as pictographs and hieroglyphs, around 3000 BCE. These symbols were used to visually convey concepts by ancient civilisations such as the Mayans, Chinese, and Egyptians. Originally used as a form of wordplay in coats of arms, rebuses were commonly used on medieval shields. The "golden age" of rebus puzzles lasted from the Middle Ages through the 19th century. From the 16th to the 19th centuries, rebus puzzles were used to make learning enjoyable in books, letters, and magazines. These puzzles concealed messages or told engaging tales by fusing words and pictures. Over time, rebus puzzles became increasingly popular worldwide [22].

As picture puzzles gained popularity in the late 19th century, they evolved into more imaginative and interactive forms throughout the 20th century, including dioramas, card games, memory games, stamp books, metamorphosis puzzles, and optical games. A major factor in this growing interest was the wide variety of puzzle types found in children's activity books [22].

There was a decline in the popularity of traditional illustrated puzzles during the late 20th century as the digital era emerged. This era brought computerised and photographic puzzles, where photo-collage techniques were introduced to create complex, multi-layered designs blending photography and art. Subsequently, picture puzzles moved from print to interactive formats, including television game shows like "Concentration," which featured visual puzzle-solving as a core activity. This introduced dynamic puzzles to a wide audience. These trends were accompanied by developments in printing and manufacturing that made mass-produced puzzles widely available, establishing them as a mainstay in both education and family recreation. This contributed to the wide social appeal and enjoyment of picture puzzles during this era [22].

The fascination with optical illusions and complex visual puzzles was sparked by influential artists like M.C. Escher. This development illustrates how picture puzzles have adapted to changes in culture and technology while keeping their fundamental allure as imaginative, problem-solving entertainment [22].

Rationale for using puzzles: A puzzle requires planning and the ability to change strategies. Tracking one's own progress improves metacognitive awareness, which impacts pattern recognition, mental orientation, spatial organisation, and visual differentiation. This tests foundational skills like navigation and creativity, where the challenges weave in knowledge of art and culture as a stepping stone toward the reward of completion. Players voluntarily engage

in problem-solving—deciding, for example, the best location for a specific piece—while choosing the path that suits them best. The game's approachability encourages better engagement, and the "Aha!" moment of finishing a puzzle motivates the player to take on harder challenges. As a result, they enter the game drawn in by the challenges that keep them invested, and leave feeling more aligned with the museum's theme [21].

5.2 Result

Usability Outcomes

Testing showed that players found the game very easy to use. More than 80% of participants confirmed this, proving that the screen layout, controls, and help features supported intuitive gameplay. Players highlighted how clear the puzzle mechanics were, noting that they quickly understood how to move, rotate, flip, and place pieces without confusion.

The mix of visual aids, such as icons for rotating and highlighting clickable items, along with Ana's voice instructions made the whole system feel accessible and welcoming. Even visitors with little experience playing digital games felt confident while navigating both the workshop and museum areas.

These findings suggest the game's design successfully balances accessibility with deep interaction. This lets players focus on learning and exploring instead of struggling with the controls. The high usability scores show not only that the screen looks and works well, but also that the educational content was carefully structured. This created a smooth start and led to players getting involved right away.

Engagement

The evaluation clearly showed that players felt a real sense of excitement about the game. Nearly 75% of participants reported they truly enjoyed the puzzles, confirming the tasks were both a good mental challenge and deeply satisfying to finish. Players especially liked how the difficulty increased gradually, which helped them improve their problem-solving skills without getting frustrated or stuck. They also appreciated the tactile satisfaction of moving puzzle elements in both 2D and 3D views.

Moving beyond the core mechanics, many individuals indicated that the experience significantly strengthened their personal connection to the artworks. The simple act of working with the art within the virtual setting, solving tasks to fully reveal paintings and sculptures and freely moving around the museum space, sparked a powerful feeling of curiosity and personal investment. The combination of sharp images, easy virtual navigation, and helpful context provided by clickable items meant visitors could appreciate the collection far more deeply than through passive viewing.

Ultimately, these outcomes establish that the game successfully engages visitors in key ways: it sharpens their thinking skills through problem-solving, connects with their feelings through the fulfilment of discovery, and achieves its educational targets by encouraging deep reflection on the museum's holdings. These results underscore the effectiveness of blending active, playful features with learning material to create a museum visit that is both meaningful and genuinely enjoyable.

Learning Impact

The evaluation showed that the game successfully increased visitors' knowledge of the art. About 65% of users said they walked away having learnt new things, especially about how Henrique and Francisco Franco lived, worked, and contributed to art. By tackling the puzzles and looking closely at the restored pieces in the virtual museum, players were able to understand the broader context: the historical and cultural importance of the artworks

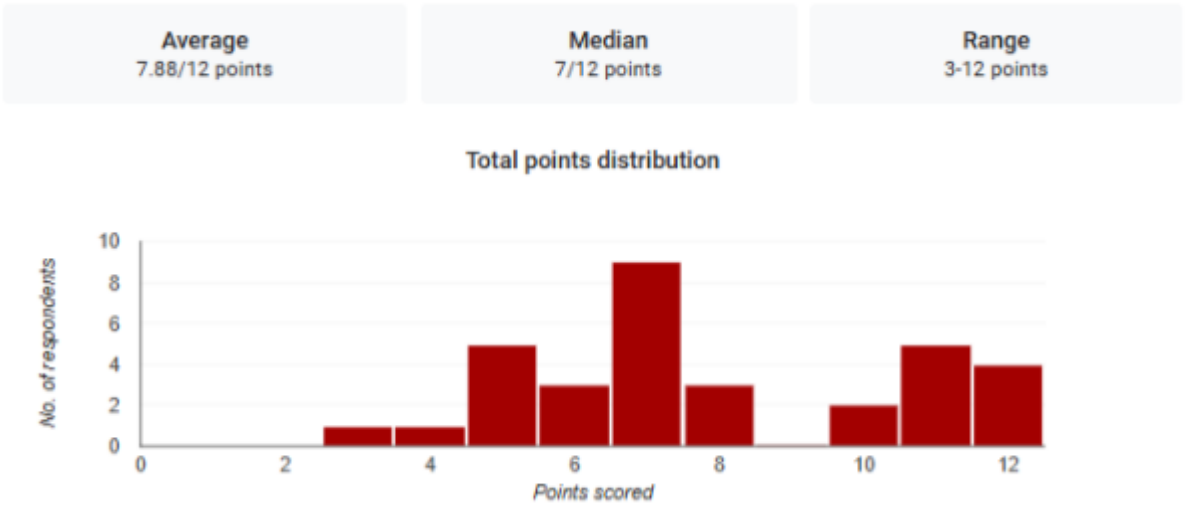

Figure 31: Thirty-three playtesters and their scores for "knowledge check" questions.

The knowledge-check questions (Figure 27) proved that players weren't just remembering basic facts; they were picking up on the small, important details of the art. This means the game encouraged them to pay attention and learn actively. Participants specifically pointed out that interacting with the art, completing restorations, and clicking for information helped them retain knowledge much better than if they had simply read a wall label.

These findings make it clear: mixing game-like fun with deep exploration works. The workshop helped players build their thinking skills, while the museum spaces solidified their understanding with real context. The whole design supports learning by creating a fun environment where being active, exploring, and reflecting lead to real knowledge gain.

Attitude Shift

The research showed a positive change in how people felt about the MHFF. Over 70% of players said that once they finished the game, they felt much more inclined to visit the museum in person. This is a significant finding because it proves the game successfully sparked curiosity, creating a clear path from the screen right to the physical building.

Younger participants, especially, were very enthusiastic. Many stated that they were now intrigued to see the actual artworks and learn more about the artists. This confirms that using games works: it creates a genuine, internal drive to learn and explore. That sense of achievement when they finally solved the puzzles and uncovered the art was the crucial ingredient, tightly linking their effort, the discoveries they made, and a deeper appreciation for culture.

Ultimately, these findings show that fun, interactive digital tools like The Missing Piece are powerful instruments for getting people excited about museums, especially those who might usually skip the visit. By blending learning with engaging gameplay, the project provides a clear model for how games can genuinely boost cultural engagement.

5.3 Limitations

Of course, not everything was perfect. Some users wanted more variety in the artworks, while others encountered navigation issues or felt the instructions could have been clearer. These are common challenges in VR projects and at the high-fidelity prototype stage, as demonstrated in previous work by Soltani and Harley [9] and Cao et al. [10].

In addition, the museum's existing hardware made it difficult to create richer graphics or more complex interactions. This reflects how smaller museums, even those with digitised content, frequently struggle to adopt VR [6]. While we worked within those constraints, it became clear that future iterations would need better technology to truly unlock the experience's potential; and to convince the management and the investors that moving in this direction is worth the cost.

Gameplay: While players generally loved the game, the feedback did point to a few clear limits that need to be addressed. Some users struggled with the controls, especially when they had to rotate puzzle pieces in 3D space. These difficulties sometimes slowed down how quickly they could finish tasks or caused minor moments of frustration.

Game Testing: Despite these challenges, most participants emphasised that the game’s supportive design mitigated potential barriers. Features such as visual cues for interactive pieces, rotation icons, hover highlights, and guidance from Ana, the digital curator, helped players stay engaged and continue learning. However, these features still need further development to become more intuitive and clear.

Project Overview: From the initial idea to the final surveys, the project faced challenges regarding time, formal permissions, and my location. These issues prevented us from testing the game as thoroughly as we had hoped and forced us to make quick adjustments. For example, by the time we were ready for testing, I had already returned to India. This meant we had less time to finish the work, and most of the testing had to be conducted online. I couldn't be there with the testers in person to observe their natural reactions or see exactly how long it took them to complete the game.

Because of this, we decided to rely on the "Knowledge Check" questionnaire. This was a way to see how closely players paid attention to the game's details in order to get the answers right. If the museum institution decides to continue with this project, most of these limitations will disappear, which will allow for much more accurate results in the future.

These current problems clearly show where we need to improve the game next. Making the game run better on older equipment, ensuring the controls feel smoother, and adding easy, optional help features will all make the game more user-friendly and welcoming to everyone. Even with these difficulties, the supportive design and engaging experience successfully kept people interested and learning, proving that the core educational idea of the game is strong.

5.4 Future Works

Looking ahead, we feel that The Missing Piece has a great deal of potential beyond this project. It is not just a prototype; it is a model that other museums, especially smaller ones, can adapt and build upon. Whether it is used within museums to enrich exhibits or in classrooms to teach history and art, the possibilities are exciting.

Due to the limited development time, some systems and mechanics were not fully implemented. These are planned for future iterations. For example, more advanced versions of the score and hint systems could be introduced. The current scoring depends solely on speed, but it could also measure accuracy. This would allow players to trade off between speed and precision based on their preferred strategy, increasing engagement for competitive individuals. The guide system currently only indicates if a piece is in the wrong position. While this works for the first phase of support, if a player remains stuck, the game could provide more specific hints, similar to the "Battleship" mechanics, with improved backend logic (a version of this exists in Level 4 but needs further work). As the goal of this prototype is to help museums with limited resources, all puzzles and spaces must be customisable. A mechanism for generating levels is needed, where an institution can input high-quality artwork, and the system automatically creates cubes as the pieces of the puzzle. Simultaneously, the solution would be generated and integrated into the AI guide and endgame systems, accounting for the artwork's complexity [20].

To implement a fully functional level-generation system, the architecture must transition from manual asset placement to an automated pipeline. This begins with a dedicated "Museum Content Management System " or backend portal where staff can upload high-resolution images of 2D paintings or 3D scans of sculptures. For 2D works, the system would apply automated height-mapping or normal-map generation to create the "3D depth" effect used in the current prototype. The core engine would then procedurally slice these models into a variable number of segments based on a selected difficulty level, ensuring that the UV mapping remains intact so the artwork looks seamless once assembled.

Finally, the backend should integrate a metadata field for "Educational Context." When a museum uploads a piece, they would also provide the historical text and audio clips. The system would then automatically populate the virtual information plaques and curate Ana's dialogue triggers for the "Discovery Room" phase. This creates a scalable ecosystem where a museum could refresh its digital exhibit weekly without requiring any further programming knowledge.

Many museums are now searching for ways to engage visitors who are used to digital entertainment. Our approach could easily fit into educational programmes where learning and fun go hand in hand. We also see this being part of larger outreach efforts, museums could share virtual exhibits with schools that don't have easy access, helping connect students with cultural experiences no matter where they live.

This idea isn't just ours, it's a growing movement. During the pandemic, as Meinecke et al. [6] pointed out, virtual access became essential, and more museums are embracing VR and digital tools as part of their future. The Missing Piece may pave the way, encouraging more museums and similar institutions to take that leap, experiment, and create experiences that are both thoughtful and accessible.

6. CONCLUSION

6.1 Summary

Through the entire process of creating, launching, and testing The Missing Piece, this project clearly shows the power that puzzle-based, interactive experiences have to revive interest in cultural history. By moving beyond passive viewing, the game encourages true exploration, sharp attention to detail, and personal discovery. It allows players to connect deeply with artworks in a way that is both digital and highly educational.

The game's design successfully combines several features such as puzzle tasks, immersive virtual travel, intuitive guides, and educational content to create a single, inviting environment for learning. This approach supports skill development, critical thinking, and mental engagement, all while sparking curiosity and motivation. Feedback from players confirmed that they not only enjoyed the active gameplay but also developed a stronger sense of connection to the museum space and its collection.

Importantly, The Missing Piece demonstrates how well-designed interactive experiences can help break down common barriers to museum engagement. These challenges often include short attention spans, a lack of prior knowledge about the art, or physical limitations that prevent visitors from fully enjoying certain artworks. By blending play, storytelling, and education, the project offers a practical, working model for how museums, especially smaller ones with fewer resources, can use technology to create immersive experiences that are both informative and fun.

Beyond immediate engagement, this project provides a clear framework for how future museum games can be built. It shows the value of refining the design over time, focusing on the user, and using both qualitative and quantitative research to create truly meaningful interactions. By valuing both the mind and the heart, The Missing Piece sets a new standard for using interactive tech solutions to spark a lifelong love for exploring and appreciating art.

6.2 Cultural & Educational Impact

One of the most rewarding outcomes of The Missing Piece has been observing how students, families, and general museum visitors engaged with Portuguese art in ways that were both enjoyable and accessible. The playful, gamified format helped dismantle the formal and sometimes intimidating atmosphere often associated with traditional museum experiences, making art feel approachable, relatable, and inviting to explore. By presenting artworks through interactive puzzles and a virtual museum, the game transformed passive observation into active participation, encouraging curiosity, attention to detail, and a sense of personal accomplishment.

By increasing players' understanding of the artworks of Henrique and Francisco Franco, the project has fostered a deeper cultural connection and pride in local artistic traditions. Participants not only gained factual knowledge about the techniques, and significance of the artists and their works, but also reported a stronger connection to the museum's collection. Knowledge-check responses confirmed that players retained details about the artworks, while survey feedback and open-ended responses revealed enthusiasm, curiosity, and a motivation to further explore art and cultural heritage.

The game also demonstrated potential for inspiring future museum engagement. Several participants expressed interest in visiting the Henrique and Francisco Franco Museum in person after playing, indicating that interactive digital experiences can act as a gateway to real-world cultural participation. This approach reframes cultural education as an ongoing adventure rather than a static lesson, highlighting the role of playful interaction in fostering exploration, discovery, and lifelong learning.

7. REFERENCES

[1] *Dong, H., Cai, Y., & Wei, Q. (2024b). The Impact of VR Museum Exhibition Design on User Emotional Experience: A Meta-Analysis. 2024 International Conference on Cloud Computing and Big Data, 144–149. https://doi.org/10.1145/3695080.3695105*

[2] *Zhou, H. (2019b). Virtual Reality in the Art Museum. SIGGRAPH Asia 2019 Doctoral Consortium, 1–5. https://doi.org/10.1145/3366344.3366441*

[3] *Delgado, J., West, R., Barmpoutis, A., Jang, S. H., Stanley, E., & Kang, H. (2024b). Enhancing Museum Experience with VR by Situating 3D Collections in Context. Proceedings of the 23rd Annual ACM Interaction Design and Children Conference, 670–675. https://doi.org/10.1145/3628516.3659372*

[4] *Yoo, K., & Gold, N. (2019b). Emotion Evoking Art Exhibition in VR. 25th ACM Symposium on Virtual Reality Software and Technology, 1–2. https://doi.org/10.1145/3359996.3365028*

[5] *Schofield, G., Beale, G., Beale, N., Fell, M., Hadley, D., Hook, J., Murphy, D., Richards, J., & Thresh, L. (2018b). Viking VR: Designing a Virtual Reality Experience for a Museum. Proceedings of the 2018 Designing Interactive Systems Conference, 805–815. https://doi.org/10.1145/3196709.3196714*

[6] *Meinecke, C., Hall, C., & Jänicke, S. (2022b). Towards Enhancing Virtual Museums by Contextualizing Art through Interactive Visualizations. Journal on Computing and Cultural Heritage, 15(4), 1–26. https://doi.org/10.1145/3527619*

[7] *Polys, N., Roshan, S., Newton, E., Narula, M., & Thai, B.-T. (2022b). Designing for Social Interactions in a Virtual Art Gallery. The 27th International Conference on 3D Web Technology, 1–9. https://doi.org/10.1145/3564533.3564562*

[8] *Schott, E., Makled, E. B., Zoeppig, T. J., Muehlhaus, S., Weidner, F., Broll, W., & Froehlich, B. (2023b). UniteXR: Joint Exploration of a Real-World Museum and its Digital Twin. 29th ACM Symposium on Virtual Reality Software and Technology, 1–10.*

https://doi.org/10.1145/3611659.3615708

[9] Soltani, S., & Harley, D. (2024b). Paintings in the Age of VR Reproductions: brookeExamining the Design of Virtual Reality Galleries. Companion Proceedings of the 2024 Annual Symposium on Computer-Human Interaction in Play, 256–262. https://doi.org/10.1145/3665463.3678815

[10] Cao, J., He, Q., Wang, Z., Lc, R., & Tong, X. (2023b). DreamVR: Curating an Interactive Exhibition in Social VR Through an Autobiographical Design Study. Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems, 1–18. https://doi.org/10.1145/3544548.3581362

[11] Ryding, K. (2020b). The Silent Conversation: Designing for Introspection and Social Play in Art Museums. Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, 1–10. https://doi.org/10.1145/3313831.3376357

[12] Wang, A., Song, X., & Lucero, A. (2024b). Linger: Extending Museum Experiences to Post-Visit Phases. Adjunct Proceedings of the 2024 Nordic Conference on Human-Computer Interaction, 1–5. https://doi.org/10.1145/3677045.3685436

[13] Ryding, K., & Fritsch, J. (2020b). Play Design as a Relational Strategy to Intensify Affective Encounters in the Art Museum. Proceedings of the 2020 ACM Designing Interactive Systems Conference, 681–693. https://doi.org/10.1145/3357236.3395431

[14] Cesário, V., Petrelli, D., & Nisi, V. (2020b). Teenage Visitor Experience: Classification of Behavioral Dynamics in Museums. Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, 1–13. https://doi.org/10.1145/3313831.3376334

[15] Løvlie, A. S., Ryding, K., Spence, J., Rajkowska, P., Waern, A., Wray, T., Benford, S., Preston, W., & Clare-Thorn, E. (2021b). Playing Games with Tito: Designing Hybrid Museum Experiences for Critical Play. Journal on Computing and Cultural Heritage, 14(2), 1–26. https://doi.org/10.1145/3446620

[16] *Paliokas, I., Patenidis, A. T., Mitsopoulou, E. E., Tsita, C., Pehlivanides, G., Karyati, E., Tsafaras, S., Stathopoulos, E. A., Kokkalas, A., Diplaris, S., Meditskos, G., Vrochidis, S., Tasiopoulou, E., Riggas, C., Votis, K., Kompatsiaris, I., & Tzovaras, D. (2020b). A Gamified Augmented Reality Application for Digital Heritage and Tourism. Applied Sciences, 10(21), 7868. https://doi.org/10.3390/app10217868*

[17] *Spence, J., Darzentas, D. P., Huang, Y., Cameron, H. R., Beestin, E., & Benford, S. (2020b). VRtefacts: Performative Substitutional Reality with Museum Objects. Proceedings of the 2020 ACM Designing Interactive Systems Conference, 627–640. https://doi.org/10.1145/3357236.3395459*

[18] *Lange, V., Van Beuzekom, M., Hansma, M., Jeurens, J., Van Den Oever, W., Regterschot, M., Treffers, J., Van Turnhout, K., Ibrahim Sezen, T., Iurgel, I., & Bakker, R. (2019b). Blending into the White Box of the Art Museum. Proceedings of the Halfway to the Future Symposium 2019, 1–10. https://doi.org/10.1145/3363384.3363469*

[19] *Tennent, P., Martindale, S., Benford, S., Darzentas, D., Brundell, P., & Collishaw, M. (2020b). Thresholds: Embedding Virtual Reality in the Museum. Journal on Computing and Cultural Heritage, 13(2), 1–35. https://doi.org/10.1145/3369394*

[20] *Andalo, F. A., Taubin, G., & Goldenstein, S. (2012). Solving Image Puzzles with a Simple Quadratic Programming Formulation. 2012 25th SIBGRAPI Conference on Graphics, Patterns and Images, 63–70. https://doi.org/10.1109/SIBGRAPI.2012.18*

[21] *Doherty, M. J., Wimmer, M. C., Gollek, C., Stone, C., & Robinson, E. J. (2021). Piecing Together the Puzzle of Pictorial Representation: How Jigsaw Puzzles Index Metacognitive Development. Child Development, 92(1), 205–221. https://doi.org/10.1111/cdev.13391*

[22] *Wattenberg, J. (n.d.). Picture Puzzle History.*

[23] *Brooke, J. (n.d.). SUS - A quick and dirty usability scale.*

[24] *https://rpac.pt/equipamentos/museu-henrique-e-francisco-franco/*

[25] *https://cultura.madeira.gov.pt/en/henrique-and-francisco-franco-museum.html*

[26] *Choi, A., Berridge, G., & Kim, C. (2020). The Urban Museum as a Creative Tourism Attraction: London Museum Lates Visitor Motivation. Sustainability, 12(22),*

9382. https://doi.org/10.3390/su12229382

[27] de Araújo, L. M., Königschulte, A., & Erb, U. (n.d.). ENHANCING VISITORS' EXPERIENCE – A SERIOUS GAME FOR MUSEUM ENVIRONMENT.

[28] Rodríguez-Vera, A. D. P., De Las Heras-Pedrosa, C., & Jambrino-Maldonado, C. (2024). Instagram communication strategies of European museums. Cogent Arts & Humanities, 11(1), 2360793. https://doi.org/10.1080/23311983.2024.2360793

[29] Smithsonian Institution Office of Policy and Analysis. (n.d.). Marketing Exhibitions: Will They Come? Smithsonian Institution, Office of Policy and Analysis. https://repository.si.edu/server/api/core/bitstreams/42f563dd-a729-474a-8da5-0b7e5a6b0da9/conten

[30] Sanfilippo, F., Tataru, M., Hua, M. T., Johansson, I. J. S., & Andone, D. (2025). Gamifying
Cultural Immersion: Virtual Reality (VR) and Mixed Reality (MR) in City Heritage. IEEE Transactions on Games, 1–20. https://doi.org/10.1109/TG.2025.3553712

[31] Castro, D. D. (2022). How Museums Reshape Audience Engagement through Social Media
Marketing. ProQuest Dissertations & Theses.

[32] Kidd, J. (2011). Enacting engagement online: Framing social media use for the museum. Information Technology & People, 24(1), 64–77. https://doi.org/10.1108/09593841111109422

[33] Kikalishvili, G. (n.d.). Social Media Strategy and Audience Engagement in Museum Boijmans
Van Beuningen.

[34] Parker, L. (n.d.). Reaching New Generations: Exploring Museums' Social Media Strategies for Engaging Younger Audiences in the Post-COVID-19 Era.

[35] McLean, F. (n.d.). Marketing the Museum.

[36] Walter, A., & Zitcer, A. (2022). Putting it All Together: How Social Media Marketing Impacts Exhibition Choices and Visitor Attendance in Midwest Art Museums

[Master of Science, Drexel University]. https://doi.org/10.17918/00001310

[37] Wilson-Barnao, C. (2017). The personalisation of publicity in the museum: From visitors to users [PhD Thesis, The University of Queensland]. https://doi.org/10.14264/uql.2017.507

[38] Drury, S. T. (n.d.). THEME PARKS AND MUSEUMS: COMPARING VISITOR MOTIVATIONS, EXPECTATIONS AND EXPERIENCES.

[39] Barron, P., & Leask, A. (2017). Visitor engagement at museums: Generation Y and 'Lates' events at the National Museum of Scotland. Museum Management and Curatorship, 32(5), 473–490. https://doi.org/10.1080/09647775.2017.1367259

[40] Duckett, C. J., Hargreaves, K. E., Rawson, K. M., Allen, K. E., Forbes, S., Rawlinson, K. E., Shaw, H., & Lacey, M. (2021). Nights at the museum: Integrated arts and microbiology public engagement events enhance understanding of science whilst increasing community diversity and inclusion: This article is part of the Pedagogy collection. Access Microbiology, 3(5). https://doi.org/10.1099/acmi.0.000231

[41] Liu, D., Xu, J., & Song, H. (2025). The Study of Social Interaction and Sense of Place in Private Art Museums of Eastern China from the Perspective of Cultural Sustainability. Sustainability, 17(18), 8282. https://doi.org/10.3390/su17188282

[42] Wang, H., Gao, Z., Zhang, X., Du, J., Xu, Y., & Wang, Z. (2024). Gamifying cultural heritage: Exploring the potential of immersive virtual exhibitions. Telematics and Informatics Reports, 15, 100150. https://doi.org/10.1016/j.teler.2024.100150

[43] Stanković Elesini, U., Miha, H., Kristan, D., Korošec, A., Protić, E., Učakar, A., Vrabič Brodnjak, U., & Rugelj, J. (2023). Mobile Serious Game for Enhancing User Experience in Museum. Journal on Computing and Cultural Heritage, 16(1), 1–26. https://doi.org/10.1145/3569088

[44] Merchán, M. J., Merchán, P., & Pérez, E. (2023). Serious Games to Enhance Education. Play, Technology and Archaeology in a Spanish museum. Revista Colombiana de Educación, 89, 59–85. https://doi.org/10.17227/rce.num89-13992

[45] Li, H., & Zhang, M. (2025). Museum game-based learning: Innovative approaches from a constructivist perspective. Frontiers in Education, 10, 1576207. https://doi.org/10.3389/feduc.2025.1576207 .

[46] https://unity.com/

[47] https://docs.gamecreator.io/gamecreator/

[48] Littleton, D. (n.d.). Music learning and child's play.

[49] Scripp, L. (n.d.). An Overview of Research on Music and Learning.

[50] Rauscher, F. H., & Hinton, S. C. (2006). The Mozart Effect: Music Listening is Not Music Instruction. Educational Psychologist, 41(4), 233–238. https://doi.org/10.1207/s15326985ep4104_3

[51] Vigl, J., Ojell-Järventausta, M., Sipola, H., & Saarikallio, S. (2023). Melody for the Mind: Enhancing Mood, Motivation, Concentration, and Learning through Music Listening in the Classroom. Music & Science, 6, 20592043231214085. https://doi.org/10.1177/20592043231214085

[52] Coffee, K. (2007). Audience Research and the Museum Experience as Social Practice. Museum Management and Curatorship, 22(4), 377–389. https://doi.org/10.1080/09647770701757732

[53] Kurbanov, F. (2023). A study of the consumer behavior as the key to expanding the museum audience. Marketing Science & Inspirations, 18(1), 27–35. https://doi.org/10.46286/msi.2023.18.1.3

[54] Museum of Art & Photography, Audience Research Project Report https://www.festivalsfromindia.com/blog/wp-content/uploads/2021/10/Audience-Research-Project-Report.pdf

[55] https://docs.gamecreator.io/gamecreator/